A STUDY OF THE UNIVERSITY ROLE IN ENGINEERING RESEARCH FOR NASA PARTICULARIZED TO THE STANFORD UNIVERSITY CASE

Final Report

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PREFACE

During World War II, extraordinary measures were taken to bring the best talents of the country to bear on problems related to our very survival. Radar and The Bomb are particular examples of developments which required the widest possible range of human capabilities, from basic science, through inventive engineering, to imaginative management. Across this spectrum, and in science and engineering in particular, university people played a vital role in cooperation with government and industry.

Today, as before, the strength and independence of our nation depend upon continued leadership in scientific and technological developments. On a broader front, such developments should continue to be central factors in the improvement of the lot of all mankind. It is generally agreed that the university scientific and technological community harbors people with special talents which are essential components for the solution of the vital problems of today, just as was the case during the war years. It is of utmost importance that we continually search for improved means of applying these talents.

Because of the gravity of the present world situation, it is sometimes suggested that the analogy with the war situation be carried to the point of diverting these university people from their academic pursuits. However, this action would ignore the different time scales in the two situations. Today we are more concerned with solutions to the long term problems. For the long haul, it is essential that we not just maintain, but greatly increase, the effectiveness of universities in the education of future scientists and engineers. No action which would compromise this basic role of the universities can be justified on the basis of immediate need. However, such a diversion of personnel is not necessary. Some universities are very successful in combining scientific and engineering research, graduate education, and useful interactions with the real world and its problems. In fact, the university people who are thus involved maintain that such a combination is essential to their central goal of guiding the metamorphosis of students into Ph.D.'s.

A further comparison with events of the war and post war years may be applicable here. Participation in the mission objectives of the war effort was no doubt an important factor in broadening the views of those university scientists and engineers who subsequently returned to their academic positions. Many of these same people now play leading roles in those universities which are most successful in combining the research, education, and interaction areas mentioned above.

From a study of the situation at a number of leading universities, it is suggested that a university can participate in a meaningful way in the solution of outstanding, real-world, scientific and technological problems of today; it can act as a focal point for the development of a regional scientific-technological-industrial complex, while at the same time strengthening its role in graduate education and research. It can do this only if at least some of the professors (there is probably an approximate critical number that must be exceeded) have a thorough understanding of both the practical and scientific aspects of their discipline, and are responsive to the broad areas of interaction of their field with scientific, technological, governmental, economic, business, legal and other factors. That is, if they are good engineers.

The program of the National Aeronautics and Space Administration is both new and of major magnitude. In a few short years, NASA support of basic research in technologies underlying the space effort has become a significant factor in many university research programs. This sponsorship of graduate education by NASA is unique in many respects. It affords a particularly exciting and attractive opportunity to focus university efforts in research and education on major national goals that are especially acceptable and challenging to the engineering and scientific community. The NASA program provides also an unusual opportunity to exploit the government-industry-university associations that have proven so productive in earlier periods.

In the course of the present study detailed quantitative information was accumulated through structured interviews with 34 of the most research-oriented Stanford faculty members in 12 divisions or departments of the School of Engineering. Exactly one-half of these faculty had research presently supported by NASA, and the remainder (with one exception) had research supported by other government agencies. Less formal interviews were held with additional members of the faculty, and with students. The interests of all (about 140) of our engineering faculty were sampled by questionnaire. In addition NASA-supported research programs were studied at a half-dozen other prominent universities.

B. CONCLUSIONS

1. Concerning engineering students and teaching we conclude that:
    a) Engineering students desire a connection between their academic program and real-world problems; this contact is not now being adequately supplied in most engineering-school curricula. (See Sec. II-E.)
    b) As a group, engineering students are highly idealistic and respond more enthusiastically to the goals of NASA than to those they associate with militarily oriented research. (See Sec. II-E.)
    c) Innovations in teaching such as the use of case studies, internships, and system-design courses are effective ways to introduce students to space problems on a realistic engineering basis. These promising instructional techniques are just beginning to be exploited and have features which should be of interest to NASA. (See Sec. II-E, Appendices B, C, and D.)
    d) The case-study mechanism offers a most attractive opportunity to broaden NASA-University contacts. Exploitation would be aided (1) if NASA were to make available to the universities suitable documentation on space engineering and research activities, and (2) if NASA were to support development by the schools of related instructional material for use via the case-study method. When generally disseminated, classroom use of this exchangeable library would direct both undergraduate and graduate student attention and interest to NASA engineering problems regardless of the orientation or degree of research involvement of the user schools. It would at the same time be most useful in the efforts of the schools to bring the excitement and challenge of real-life problems into the classroom. (See Appendix D.)

SUMMARY

A. INTRODUCTION

This is a study report on the university role in engineering research for the National Aeronautics and Space Administration, with particular reference to the Stanford University Engineering School. It was undertaken as a result of discussions between NASA and University personnel regarding the relative lack of attention being given at universities to important problem areas in space engineering as compared with the emphasis that has been given to scientific activities in particular, and NASA-University relationships in general.

A second objective has been to examine and report on the research practices, program character, the attitudes of the faculty and students, and the administrative problems that have arisen in carrying out the NASA program in a particular School of Engineering. While no school represents a "standard sample," Stanford has a six-year history of interaction with NASA and the current NASA program represents a major component of the Stanford total. Thirty-four NASA grants and contracts were in operation at the end of 1964 in five Schools and Divisions within the University. The largest number (twenty-one) were in the School of Engineering. All of these arrangements resulted from matches of interest established by individuals in the University with NASA. (Stanford has no NASA institutional grant in support of research.) For these reasons, the exploration of the Stanford pattern is thought to be useful in assessing the impact and influence of the NASA program on the research environment in a School of Engineering.

Although the study has been made in the context of the Stanford engineering community, other inputs have also been used, and many of the results of the study are believed to have a general applicability to NASA-University relations. Some of our conclusions will be controversial, and we recognize that opinion, personal experience, and the influence of a local environment play an important role in a study of this type. We offer this report as a statement of the findings and conclusions of an introspection at a single university engineering school with respect to its academic aims, and their relationship to the national space program, other universities, and the technical community.

3. Concerning the character and organization of faculty research, we conclude that:

   a) The Sustaining University Program of NASA is imaginatively conceived and well administered. It provides the most important support components by NASA for universities, and is effective in stimulating significant university response to national space goals. (See Secs. III-A and III-B.)

   b) University contributions to the NASA effort (and vice versa) have grown rapidly in the recent past. Interest in the national space goals is continuing to grow, and even those universities with active research programs possess a large untapped reservoir of competence available to meet the needs of the space program. (See Sec. II-F, Appendix A.)

   c) Despite the relatively deep involvement of the Stanford Engineering School in NASA research, the specific contacts involved in the conduct of this study stimulated a good deal of new faculty interest in the national space program as a focus for graduate research. As a by-product, a substantial number of new suggestions arose for contributions to the space effort. It thus appears that the normal efforts over a several-year period of University and NASA publicity to generate such an interest and awareness were incompletely successful.

   d) To maintain program continuity, research oriented faculty typically seek support from several agencies concurrently. Faculty members generally consider agency proposal-review procedures to be of high quality, and value the opportunity for reviews outside the university. (See Sec. II-F.)

   e) When faculty research is supported primarily on a project basis, achieving financial stability and flexibility is a major faculty concern, and the time spent in securing and administering these grants is a heavy drain. (See Sec. II-F.)

4. Concerning university contributions to space-flight projects (faculty research for NASA), we conclude that:

   a) University contributions to space-flight projects can profitably extend beyond scientific experiments to aspects of mission planning and engineering design. (See Secs. IV-C and D, and Appendix B.)

   b) The complexity of the organizational interfaces between universities, NASA Headquarters and Centers, and industry make university participation in major flight projects very difficult. (See Sec. III-C.)

   c) As seen from a university, there appears to be excessive compartmentalization of responsibility and lack of communication in control of certain space-flight projects, resulting in increased cost through lack of information or misinformation, and interface complexity. (See Sec. III-C.)

2. Concerning research and graduate education we conclude that:

a) The NASA support of basic investigations in a variety of disciplines underlying the overall space program represents a very important component of University research. Roughly half of the current NASA grants in engineering at Stanford exhibit this "science" orientation (in contrast to space-flight projects). The conduct and administration of these projects by NASA is smooth and efficient with proposal turnaround time representing the principal problem to the University. (See Secs. III-A and III-C.)

b) A university space program requires students and faculty whose interests range from nearly pure science to emphasis on applications. A few are needed who are strong in both areas. The existence of this blend is a source of strength at many engineering schools. (See Secs. II-B through II-D, and IV-D.)

c) Space programs are characterized by multidisciplinary cooperative ventures. An engineering school needs focal mechanisms to draw student and faculty attention to topics best approached by cooperative efforts. When related to space goals, the teaching innovations mentioned in Conclusion (1) are effective ways to spotlight NASA problems. (See Secs. IV-B and IV-C, and Appendices B, C, and D.)

d) Space-flight projects can also provide a focus for cooperative research in engineering. University participation can range from direct project responsibility to more basic theoretical and laboratory work slanted toward project problems. (See Sec. IV-D.)

e) Graduate students can obtain advanced degrees by contributing to flight projects whose length from inception to completion is longer than their graduate university careers, if at their school there is a "steady-state" participation in flight projects. If at a given time, there exist projects at various levels of development, from future planning to analyzing and studying results of previous flights, the students can then become aware of the broad aspects of space experimentation and space technology at the same time that they are probing in depth for a dissertation topic. (See Sec. IV-E.)

f) Comparison of Stanford faculty members naturally attracted to and now receiving support from NASA with a comparable group receiving support only from other agencies shows the NASA-supported group to have a larger number of involvements with Government and Industry, to supervise a larger number of graduate degree students, and to carry comparable loads in classroom teaching. (See Sec. II-F.)

d) Although the universities should avoid developing a complex organization to deal with interface problems, a professor involved in flight programs needs highly competent administrative support to buffer him from the innumerable detailed problems that arise from daily contacts. Support of this sort is not ordinarily needed in other areas of university research. (See also Secs. III-B and III-C.)

e) Since in many cases booster costs no longer exceed spacecraft costs (and booster considerations are less influential in experiment design), it would appear profitable for NASA to examine whether or not a relaxation in the degree of administrative control of spacecraft-experiment instrumentation procedures might not be suitable for certain classes of experiments. Such procedural changes could add significantly to the opportunities for university participation. (See Sec. III-C.)

f) More widespread NASA support of space-oriented university programs in ground-based disciplines (such as radio astronomy) could contribute substantially to the attainment of NASA goals in space. (See Sec. III-B.)

5. Concerning university-community interaction and spin-off, we conclude that:

a) Research reports and technical papers serve as effective communication media between research groups; however, they very often do not serve to excite the interest of industrial organizations or contribute materially to the direct transfer of technical information from a university to such groups. (See Sec. II-D.)

b) Receptive attitudes and specific actions are required within the University, Industry, and often by the Government sponsor in order to generate a more than casual relationship between a university and the surrounding community. Proximity alone is insufficient. Effective means for promoting interaction have included the establishment of industrial affiliates programs, and the presentation of formal, open reviews of university research. Among other effective methods are the opening of technical seminars within the university to the local community, the sponsorship of summer institutes, and the seeking of qualified university lecturers from the local community.

c) Important products of university programs are the supply of trained personnel, the availability of competent faculty advisors (to Government and Industry) and the less tangible influences resulting from the development of new technologies and research breakthroughs. Excellent evidence of the profitable interaction that can occur is offered by the demonstrated impact of universities strong in research and engineering on the likelihood of success of a nearby "Research Park." (See Sec. II-D.)

d) The development of major practical fall-out from university research programs often is not fully evident until 5 to 10 years after the initiation of the research, and may continue to rise in importance for as much as 30 years. Patience, together with continuity and flexibility of support, is essential in the funding of competent and well motivated research groups. (See Sec. II-D.)

e) Generation of an industrial fall-out from university efforts requires organized planning and encouragement by the university. This process is greatly aided if the university faculty includes a nucleus of highly competent professors who combine an interest in both research and its applications. Within an engineering school such composite interests are not uncommon. (See Secs. II-C and II-D.)

6. Concerning NASA funding of university research, we conclude that:

a) Project funding of university research has many benefits. The external review is valued and appreciated. The opportunity to match funding in amount and assignment to project goals is helpful. The independence of action (as opposed to an internally controlled distribution) is attractive to many faculty. (See Sec. II-F.)

b) There are undeniable attractions to the institutional grant as a funding mechanism. This is strongly felt by faculty who are not natural "salesmen," and by some within the university administration. There may be fewer administrative complications, and there are substantial benefits to the university in covering funding gaps, in expediting support of logical research spin-off's, and in promoting program coherence. Step-funding as practiced by NASA is a substantial assistance in maintaining program continuity. (See Secs. II-F, IV-E.)

c) Faculty opinion and administrative experience both suggest that a combination of institutional grant and project funding would best assure both appropriate attention to research geared to NASA goals and flexibility in administration. An attractive arrangement might involve 25 percent of program funds handled through the broad grant, with a periodic review and adjustment of the amount of these funds to maintain the proportion to the project activities within the total program. (See Sec. IV-F, Appendix E.)

d) Viewing Government support as a whole, no clear case emerges for grants as against contracts. Grants tend to be more flexible and are thus attractive to a university. But this is not universally so, and contracts are sometimes no more restrictive than grants. Full recovery of research costs through an audited contract has a value often not fully appreciated by research faculty. In short, the relative attraction of grants and contracts depends on the conditions of the specific instruments being compared. (See Appendix E.)

e) Experience at Stanford has been favorable with a form of blanket contract into which new funds (earmarked for specific new endeavors) can be conveniently transferred with a minimum of administrative complexity on the part of the sponsor and the university. It would appear that such an arrangement could be profitably explored as a partial funding instrument in the case of broad program arrangements between NASA and the universities. (See Appendix E.)

f) There are good reasons from the University viewpoint in favor of direct funding arrangements between the university and NASA in cooperative ventures involving industry (in cases where detailed control by the university is not vital to performance of university project objectives). The role of the university either as contractor or subcontractor with respect to the industrial partner has presented substantial difficulties in administration and control of program character. While the university would argue for a maximum flexibility in information exchange and program conduct within the triangle, we would prefer that broad program control remain with NASA and that the funding ordinarily be direct. (See Appendix E.)

I. INTRODUCTION

In the Space Science Summer Study of 1962, it was noted with respect to the program of the National Aeronautics and Space Administration (NASA) that "in spite of the fact that space engineering rather than space science accounts for by far the largest part of NASA's budget, NASA does not seem to have developed a recognizable policy toward engineering education, probably because engineering education itself is in a state of flux."

The above quotation is from the chapter of the Summer Study report on NASA/University Relationships[1], in a short section on research in systems engineering. The present study may be looked on as one indication that NASA does indeed take a continuing interest in engineering-education policy. It is concerned with the university role in engineering research for NASA, and uses a detailed examination of the Stanford University experience as an example. The study is an outgrowth of several discussions held between high officials of the Space Administration and administrators of Stanford University during 1964, regarding the possible mutual benefits of such an investigation.

The advantages of participation by the university community in the basic research aspects of the space-science program have been well demonstrated. However, relatively little attention has been focused on the possible interaction between graduate education and engineering research at a university, and on the broad engineering problems involved in current and future NASA missions. Individual professors of engineering have contributed to isolated aspects of both the science and technology of the space effort, but few attempts have been made to use the interdisciplinary flexibility inherent in an engineering school for the coordination of productive attention to areas of broader interest to NASA.

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[1] A Review of Space Research--the report of the summer study conducted under the auspices of the National Academy of Sciences at the State University of Iowa, June 17 - August 10, 1962, Publication 1079, National Academy of Sciences, 1962.

Some very basic questions arise here. What constitutes engineering research at a university? Is there, and need there be, a clear distinction between engineering and science? Can the university direct attention to NASA mission objectives without impairing the individual initiative and freedom of choice which are so fundamental to faculty research programs at a university? Would graduate students benefit from such an educational environment as they pursue an education and perform research for advanced degrees? What approaches should be used to insure the maximum flow of research results to NASA and to the governmental and industrial community as a whole, and to the economic and technological community with which the university is associated?

These questions have components which go beyond the scope of this study. We will concentrate here only on certain aspects of the NASA-engineering school problem. The broader problem areas have been, and are still being, studied by a number of individuals and advisory groups. We mention in particular the "Seaborg,"[2] "Gilliland,"[3] and "Kistiakowsky"[4] reports and, with regard to NASA/University relationships, the previously cited summer study report of the National Academy of Sciences (Ref. 1), reports of NASA/University conferences,[5,6,7] and a report by a university man on leave of absence to NASA.[8]

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[2] "Scientific Progress, the Universities, and the Federal Government," statement of the President's Science Advisory Committee, Government Printing Office, Washington, D.C., November 1960.

[3] "Meeting Manpower Needs in Science and Technology," a report of the President's Science Advisory Committee, Government Printing Office, Washington, D.C., December 1962.

[4] "Federal Support of Basic Research in Institutions of Higher Learning," Committee on Science and Public Policy of the National Academy of Sciences, Pub. No. 1185, 1964.

[5] "NASA-University Conference on the Sciences and Technology of Space Exploration," November 1-3, 1962, NASA SP-11.

[6] D. J. Montgomery, "Summary Report of the NASA-University Program Review Conference--Kansas City, Mo., March 13, 1965," NASA SP-81.

[7] A report on the Kansas City NASA/University conference of March 13, 1965 is in preparation.

[8] "Final Report--A Study of NASA-University Relationships," by S. G. Roth, GPO 879-280, Government Printing Office, Washington, D.C., 30 June 1964.

The approach used in the present study has involved looking inward at the Stanford situation. Interviews were held with engineering faculty, students, and administrators regarding engineering research, teaching, graduate education, and program management. The present conditions have been investigated, problem areas studied, and future possibilities and potentialities explored. A limited number of other educational institutions have been visited and their programs and problems compared with those at Stanford. Talks have been held at NASA headquarters to gain a better understanding of the NASA viewpoint, and special study has been made of areas of interaction between Stanford University and the nearby NASA-Ames Research Center at Sunnyvale, California. The past history and present programs of university interaction with the industrial community of the San Francisco Peninsula have been studied, and suggestions are made with regard to the role of such interaction in the development of both the university and the community.

We stress in particular the definition of engineering research in a university, its connection to the graduate student program, its possible contributions to and interplay with broad NASA missions and the technological community, and the conduct and administration of a sample engineering school program in space science and technology. While references and examples are related primarily to the Stanford University situation, practical extrapolation to the general case of the potential NASA-University engineering research relationship is inherent.

II. GRADUATE EDUCATION AND ENGINEERING RESEARCH

A. INTRODUCTION

Engineering research is difficult to define. One is tempted to say merely that engineering research at a university is the kind of research being done within schools or departments of engineering. But more can be said than this. Certainly one could differentiate engineering research from scientific research in general at a university by noting that engineering research often involves more application to human needs, involves more breadth in terms of the use of results and techniques from many different disciplines, is characterized by more responsiveness in research topic selection to human, social, economic, national prestige, and national defense problem areas, and involves a planned interaction with the technical community as a whole. Engineering research is undertaken with the intention of ultimately modifying or using the human environment, rather than merely understanding it.

Engineering schools are in a state of flux, and as a result graduate education and research in engineering schools cannot be neatly categorized. In the years since World War II many engineering schools have made giant strides in increasing the basic science content of their curricula.[9] In research, they have made fundamental contributions in areas where basic mathematics and physics have played leading roles; science is now a regular and necessary ingredient in engineering curricula. Courses and dissertations on solid state physics, mechanics of solids, process dynamics, statistical communication theory, computing, theory of systems, quantum electronics, plasma dynamics, nuclear sciences, astronautics, turbulence theory, or physical metallurgy, as examples, bear little resemblance in treatment or topic to engineering school courses and dissertations a decade or two ago. Nonetheless, there is concern that too many engineering schools still regard as their prime function the professional training of students

[9] F. E. Terman, "The Newly Emerging Community of Technical Scholars," Colorado and the New Technological Revolution, Proc. of the University-Industry Liaison Conference, April 1961.

in empirical design. With insufficient science content in their curricula, such students will be unable to cope with a rapidly changing technology.[10]

On the other hand, we are beginning to hear complaints that the pendulum of science in engineering education at the leading universities has swung too far, or at least that the emphasis on science has detracted from the real world, application aspects of engineering. In his book Foundations of Engineering[11], Philip Sporn notes that, "cumulative changes in the curricula of our colleges of engineering have shifted the emphasis from engineering to science--mathematics, physics, chemistry--and, concurrently, have led to the neglect of some of the long established basics of engineering... Overnight, schools of engineering have blossomed out as schools of applied science." Prospective students "have been led to believe that engineering is an outdated pursuit that today cannot challenge a high-grade intellect...the really constructive work, they are repeatedly told, is done by scientists." There is concern that students of broad and creative abilities who are so badly needed in engineering have been replaced by men of narrow, highly specialized, mathematical and scientific interests. Note that this concern is with the nature rather than the extent of formal education; the Ph.D. in engineering is a logical goal for qualified students.

As will be evident from subsequent discussions, we too see cause for concern about an excessive emphasis on science in engineering education. We believe that the inclusion of science is necessary and should receive continuing stress. But the exciting goals of the future, we believe, will not be achieved without emphasis on broader involvement in areas of engineering practice to match that in science. Such involvement is central to the definition of engineering. Promising new developments of this sort are taking place in several of the leading engineering schools.

In the remainder of this chapter, we provide some guidelines to what we believe constitutes progressive engineering research and graduate education at a school or college of engineering; we also give some examples

[10] H. G. Booker, "Academic Organization in Physical Science," Science, 146, pp. 35-37, 2 October 1964.

[11] Philip Sporn, Foundations of Engineering, Macmillan Publishing Company, 143 pages, 1965.

of significant interactions with the needs of our government and the growth of industry, and summarize student and faculty viewpoints on the situation at Stanford. We justify the emphasis on self-examination on the grounds that such information can be of value to NASA in assessing its role in education.

B. ELEMENTS OF ENGINEERING RESEARCH AND GRADUATE EDUCATION

In this section we discuss briefly certain general elements of a total engineering research and graduate education program which are central to, and set the tone for, our later discussion of more specific aspects of potential NASA-engineering school relationships. Some examples of the forms these relations may take are included in later sections.

In the classrooms, emphasis is needed on both depth and breadth. Only with depth in basic mathematics and physics will the graduate engineer be able to contribute to, or even cope with, the rapidly changing technology. At the Ph.D. level, a dissertation that represents a basic and real contribution to knowledge is as essential in the engineering field as it is in any science discipline. For the bachelor, master, and engineer degree students in engineering, mathematics and physics are his basic tools, and he must be able to use these tools with imagination and resourcefulness.

Yet if the engineer is to be differentiated from a graduate in the physical sciences, an extra measure of breadth is called for. This breadth must come from the motivations of the students and their professors, from a shade of difference in the presentation of classroom material on subject matter which in a nonengineering school might be representative of pure science, from a curriculum of study that includes examples of the application of the basic sciences to practical problems, and from the choice of research topics for advanced degrees. For the professors, this breadth can probably not be maintained unless they continue to interact--by means of research, publications, meetings, consulting and advising with the outside world. For the students, they will be good engineers sooner if they can join in some of these exciting and demanding interactions, as responsible participants, while still working for their advanced degrees.

Indeed, such experience may be necessary to capture student interest in engineering as a career before they become committed to the better-ordered world of pure science.

In addition to the question of individual breadth is the question of breadth in the engineering school structure and activities. It is unrealistic to expect that each professor and each graduate student can be a leader in both basic science and in applied engineering. Some are, but most have a narrower range of competence, directed to depth in a specialty; their interests can be characterized as being primarily basic on the one hand, or applied on the other. An engineering school of sufficient size can well afford to include in its faculty and programs a relatively cloistered basic research group. For a smaller school, the function of such a group (from the point of view of the engineering school) could be carried out in part by other departments in the physical sciences, if efficient communication channels between the two faculties are maintained by interested individuals in both areas, and if joint programs involving graduate students from both departments are undertaken.

One might characterize a university by using a model based on the structure of an onion, with the various concentric shells representing various depths and isolation from the outside world (see Appendix C). At the center would be the highly theoretical, very "pure," parts of mathematics, science, biology, medicine, history, philosophy, i.e., those who are most analytically oriented. The outer skin would represent those faculty, students, and programs which are most intimately connected with the outside business, industrial, and human society, including parts of engineering, the business school, law, the medical intern program, and those most concerned with synthesis and external action. It is essential that an engineering school have a working real-world interface at this outer level. It also requires roots into the central core of basic mathematics and physics; while some of these roots might be based on good communications, at least a part should be built around individuals on the engineering faculty.

Concurrently, we hear objections that either (1) engineering as taught is too superficial, or (2) that engineering schools have withdrawn into the isolated university core of pure science. We suspect that both problems exist but that the concern is exaggerated because of the differences in the positions from which the critics take their views. Good engineering schools must have strength in both the "pure" inner and "applied" outer shells of the "university onion." Viewed from the corresponding vantage points, the balance of the university program will look quite different.

Our own conclusion is that sufficient scientific emphasis does now exist at the better engineering schools. Because these schools are trend setters, we are most concerned that the emphasis on pure science in some of the prominent schools should not act to the detriment of the applied aspects of engineering. This process can grow and be self perpetuating. New faculty are now usually chosen from the best new graduates, instead of from professional people who have had outside experience. Often the measure of the talents of a young graduate is based upon his theoretical ability as evidenced in his Ph.D. dissertation. The stage is thus set for progressive inward withdrawal from the outer onion skin, unless measures are taken to include aspects of the real-world interface in the graduate education and research of prospective engineer-scientists while they are obtaining advanced degrees. This is one of the themes that we wish to stress in this report, and other aspects of it will be referred to again.

The requirement for an intimate connection between graduate education and research has been referred to again and again in the various studies mentioned earlier. We assume that this requirement is well understood, but will quote a few sentences from the "Seaborg" report to illustrate the emphasis that has been used:

> "...In all forms of scientific work a man's effectiveness is multiplied when he has the depth of understanding of his subject that comes only with the experience of working at a research problem....we insist on the central point; the would-be scientist must learn what it is like to do science, and this, which is research, is the most important thing that can be 'taught'....These young people do not easily study what is not taught; they do not often learn the meaning of research

which does not exist in their environment....research, learning, and teaching are deeply connected processes...."

That the intention was to include engineering and engineering research in the sense of the above statements on science and scientific research is evidenced from other statements in the same report, including,

> "...one striking characteristic of our scientific age has been the disappearance of the barriers between pure and applied science... Part of the strength of American science stems from close intellectual intercourse between basic and applied scientists. Very often, indeed, the same man can be both "pure scientist" and "engineer," as he works on different problems or on different parts of one problem. We do not believe in any artificial separation between basic and applied research or between science and engineering. The fact that a scientific advance is useful does not make it unscientific."

In our discussion of graduate engineering education and research, we wish to stress the breadth of the engineering discipline in terms of the tradition of involvement, practicality, and application coupled with depth in the basic physical sciences. Another approach might lead to a similar end point. For instance, H. G. Booker, while at Cornell University, has recently decried the lack of academic organization in physical science.[1] Usually the physical sciences in a university are illogically split by major administrative divisions. Booker cites an example of plasma physics which is studied at a particular Ivy League university:

> "in its laboratory form in the department of aerospace engineering, in its upper-atmospheric form in the department of electrical engineering, in its cosmic form in the department of astronomy, and in its solid-state form in the department of physics. Of these four departments, two are responsible to the dean of engineering and two to the dean of arts and sciences....Yet it only takes one dean...to handle such diverse subjects as quantum theory and Greek literature."

Booker includes in his definition of physical science in a university,

> "departments dealing with theoretical physics, experimental physics, observational physics, and applied physics; with present university organization this area includes the dynamic part of the Engineering College."

A starting point encompassing the tradition of the physical science areas in a university, including applied and observational research, and adding an area of application and involvement, might lead to an organization that

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[1] Booker, H. G., see footnote reference page 5.

would be nearly indistinguishable from the broad engineering school we are attempting to describe here.

C. THE DEVELOPMENT OF A PATTERN OF UNIVERSITY-INDUSTRY-GOVERNMENT RELATIONS IN THE STANFORD COMMUNITY

In considering NASA-University relations in engineering, and their interactions with industry, we have looked in particular at the Stanford example. To give some perspective to this view, we shall in the present section discuss the historical growth of engineering at Stanford in relation to the development of the local technological community. In Sec. II-D we shall then elaborate on this theme with examples illustrating the effect of specific university programs.

At the end of World War II Stanford was a university which had participated in wartime research to only a very minor extent, and which was located in an area containing but a handful of small engineering firms. Its students and engineering staff had been largely dispersed, and the facilities and funds for research were meager. Today the university is a major center for engineering teaching and research, and its electrical engineering department trains more Ph.D.s than that of any other school. Surrounding the university is an industrial complex in electronics and aerospace engineering, a combination which is frequently cited as an example of felicitous development of university-community interaction. In addition to such firms as Lockheed, Varian Associates, Ampex, and Hewlett-Packard, the peninsula region contains laboratories of General Electric, Philco, and Sylvania, together with over a hundred other research-oriented companies, and the Ames Research Center of NASA. A substantial number are included in the forty-odd tenants in the Stanford Industrial Park.

These technically sophisticated firms exist in a symbiotic relationship with Stanford which has a number of mutual advantages:

1. a. The university supplies industry with a local and easily recruited supply of highly trained engineers.

   b. Industry benefits the university in turn by supplying challenging jobs to graduates close at hand, in an area they have frequently found attractive.

2. a. The university supplies ideas and research results to industry; the technology-utilization pipeline is very direct.

   b. Industry gives the university faculty the chance to see their ideas carried to fruition, and provides the stimulation of presenting practical problems for solution.

3. a. The university provides specialized competence and support in the form of faculty consultants.

   b. Industry provides the faculty with an opportunity to gain experience as consultants in a broad spectrum of problems, and to augment their income in the process.

4. a. The university supplies the opportunity for graduate education to students employed in industry through part-time enrollment.

   b. Industry provides the university with mature and well-motivated graduate students.

5. For both industry and the university, an overall environment arises of creativity, stimulation, and growth.

It is worthwhile to document the metamorphosis of engineering at and about Stanford in the past 15 to 20 years, since such knowledge is helpful to efforts to maintain and develop the environment, or to duplicate it elsewhere.

It is undoubtedly true that many factors affected the growth of both the University engineering and science programs and the surrounding industries, and the seeds go back at least 30 years (if not to the historic early activities resulting in the invention of the triode vacuum tube oscillator in Palo Alto by Lee deForest in 1912). While none of the fortuitous factors influencing the growth of the research complex should be minimized, the most important factor was a conscious awareness of opportunity, and an active courtship and stimulation of a viable university-industry relationship. The dominant figure in the development has been Dr. Frederick E. Terman. In the 1930's he served as Professor of Electrical Engineering and Department Head, and during World War II went to Harvard to serve as Director of the OSRD-sponsored electronic warfare work of the Radio Research Laboratory. He returned to Stanford after the war to serve as Dean of Engineering and Director of the Stanford Electronics Research Laboratories, and later as Vice President and Provost of the University. His leadership was compounded of enthusiasm, clear insight, an enduring goal, and a great deal of hard work.

What factors influenced the development of the university-industry complex? Back of each individual decision lay an enduring image of the mutual benefits of integrated university-government-industry cooperation. The image took form through hard work, a flexible, adaptable approach, and by recognizing and taking advantage of the opportunities of the times. The specific circumstances and opportunities that led to the Stanford area growth will never be exactly duplicated, but other opportunities will arise at Stanford and elsewhere, at different times, and in different fields.

A vital, but philosophical, aspect was the exploitation of the concept that engineering extends beyond analysis and includes the practical implementation of an idea. The engineer is not content to study nature. He wishes to apply what he knows to build something new, or to modify the environment to man's benefit. As early as 1938, two of Professor Terman's electrical engineering students, (Hewlett and Packard) felt impelled to manufacture a novel electronic oscillator circuit developed on a thesis project. This was the genesis of a very large corporation. The attitude that implementation is the ultimate goal of engineering was essential to the action. As Packard recently said, if his major professor had been espousing civil disobedience instead of productive engineering, his career would have taken a different direction. It is in this essentially executive attitude that the essense of engineering lies.

Consider now some of the factors that applied to the Stanford example, and whose recognition and development led to growth.

1. An obvious asset of the Stanford area is climate, and that the San Francisco Bay Area is a good place in which to live. The economy as a whole has grown rapidly. Homegrown engineers hate to leave, and others are happy to come. There is good access by air to all major cities. These characteristics, of course, are possessed by many communities which have developed little research-oriented industry.

2. During the war, Dr. Terman collected an outstanding and predominantly young staff of engineers and scientists to work on electronic warfare problems in Cambridge, Massachusetts. Many of these researchers, impressed by Dr. Terman's leadership and subject to strong salesmanship by the California contingent of the staff, decided to attend Stanford after the war. They provided a nucleus of students oriented to government-supported research, and helped compensate for

the lack of major research activity at Stanford during the war. The return to school of many mature veterans after the war also contributed to the potential strength of the school.

3. Stanford as the major private university in the west was in a somewhat unique position of opportunity. In some fields, including electrical engineering, faculty members possessed reputations which attracted students interested in the broad aspects of engineering.

4. After World War II a new pattern of financial support of research at universities developed. The availability of contract support for research from the Office of Naval Research and other agencies made it possible for those institutions that were responsive to the agency needs and that were quick to adapt, to build up their programs rapidly.

5. In 1946 the Board of Trustees of the University established the Stanford Research Institute as an independent nonprofit corporation devoted to performing research for industry and government. The Institute has been a mainstay of the area's research activities in the years since then.

6. In addition to the activities in engineering, programs were developing in physics before and after the war which culminated in practical developments. The high-power klystron tube grew out of research directed toward design of high-energy linear electron accelerators. The 2-mile-long electron accelerator currently being constructed on the campus with Atomic Energy Commission funding of well over $100 million is an outgrowth of physics research starting in the 1930's. A considerable industrial base is related to its construction and maintenance.

7. The university has actively encouraged the buildup of industry within its environs in a number of ways. A site, known as the Stanford Industrial Park, was developed on Stanford land and plots were leased to light industry for controlled uses. Certain university facilities were made available for industrial use. An Honors Cooperative Program was initiated in which selected industrial degree students are allowed to register for courses on a unit basis, while continuing their work with their company. Special annual technical presentations were devised to keep industrial firms apprised of the latest university research results. Industrial Affiliates programs were started whereby the industrial firms were given access to Stanford research results and the industrial firms in turn provided the university with financial assistance.

8. Every effort was made to strengthen the faculty with key personnel of the highest quality, and with an interest in and understanding of both theoretical problems and their practical applications.

As a result of the University's acceptance of the desirability of active cooperation with industry and government, and of a conscious effort to actualize the opportunities, a phenomenal growth took place. This growth was evidenced both by rapid expansion in university research activities and by the development of a strong technically based local industry. Some firms were started with Stanford faculty participation; some were formed to exploit outgrowths of the research program. Many of the large organizations are branches of national firms who saw advantages to locating laboratories in a center of brains and technical foment formed by their industrial associates and the University.

In the whole development, the University has played an active role. University people have sought out industrial people, gotten acquainted, learned their problems, and recognized them as equal partners. The university has encouraged the approach of industry by its readiness to receive them, by supplying building sites, conducting open seminars, consulting, by holding joint memberships on professional society committees, by inviting industrial lecturers, and by making special arrangements for part-time industrial students.

Development of a university-industry relation cannot, however, be forced. It is based on mutual advantage, and the university, for its part, must offer competence and opportunity in formal education, and an active research program that is a source of ideas and a stimulation to practical applications. In this regard there is no substitute for the acquisition by the university of outstanding faculty members to serve as a nucleus for further development. Their own competence then becomes multiplied manyfold by the students and associates they draw to them.

Once well established, a program of university-industry cooperation generates a certain momentum which carries it on. As in a chain reaction, the attitudes are contagious. However, times continually change, and if a program is to remain alive and exciting, continuous adaptation is necessary--in research directions and in educational opportunities. In the context of the Space program, new mechanisms of interaction are needed, but still based on the overriding philosophy that the goal of engineering is implementation and that the universities and in this case, NASA, will gain mutual advantage from cooperation in the closest way.

D. EXAMPLES OF ENGINEERING RESEARCH PROGRAMS AT STANFORD, AND INTERPLAY WITH RESEARCH AND DEVELOPMENT ACTIVITIES IN THE SURROUNDING AREA

In this section we shall first look backwards and examine two major research programs at Stanford which have had long and productive histories. From this examination we shall hope to learn something of the nature of "spinoffs" and the time scale with which important applications occur. We hope also to elucidate the relation of certain aspects of the research environment, and of flexibility of project direction, to overall research effectiveness. After our look backwards, we shall consider the present situation at Stanford with emphasis on the types of interactions which exist between the University and the outside community (including the Ames Research Center of NASA), and the part they play in promoting practical applications of research results.

Our first example of research program development starts over 30 years ago in the Stanford physics department; the end is not yet in sight. It began in 1933 when physicist W. W. Hansen set himself the problem of constructing a new type of high-energy electron accelerator. The method which he envisaged--based on accelerating electrons under the urging of an electric wave--required a technology that had not yet been invented. Hansen hence concentrated his attention on the technical problems; working with modest funding he and his associates invented the cavity resonator. In 1937 the Varian brothers invented the klystron tube (which uses the cavity resonator as a basic element) in Hansen's laboratory. Hansen played a dominant wartime role at the MIT Radiation Laboratory and at the Sperry Gyroscope Company in aiding practical use of these new microwave techniques.

Following the war the Stanford Microwave Laboratory was formed as a joint undertaking of the Physics and Electrical Engineering Departments. For many years its activities were focused on the development of high-energy linear electron accelerators.

One of the major requirements for such an accelerator is a high-power source of microwave energy. In 1949, the Microwave Laboratory converted the klystron from a hand-sized tube useful in radar receivers to a multi-megawatt device. Later models were developed which normally run at power levels of 15 million watts. In late years the high-power klystrons, which had been built because of a need for a linear-accelerator energy source, were adapted for use as a radar power source. While these and other developments from the Microwave Laboratory have proved to be of immense value to the Defense Department, it is worth noting that they were not conceived in response to a set of narrowly defined objectives. (The first linear accelerator, just 12 feet long, was built in 1947, two years prior to Dr. Hansen's premature death in 1949.)

The interest and competence which the Microwave Laboratory achieved in high-power tube technology led to study of other forms of beam-type microwave tubes, with the result that the Laboratory developed the first suitable circuits and technology for a pulsed traveling-wave tube (TWT) handling powers above several kilowatts. The TWT circuits first investigated and tested in the Microwave Laboratory have provided the basis for practically every successful high-power traveling-wave tube now under development or production anywhere in the world. For example, every multi-megawatt traveling-wave tube in use in military radar systems, the TWT's used in almost every phased array under development in this country, and the TWT's in all ground transmitters for satellite communication each use a circuit either first invented or first developed in the Microwave Laboratory.

Since the early 1950's, the accelerator development program has continued, culminating first in construction of a 300-foot machine with an ultimate energy of over a billion Mev. Physics research conducted with this machine led to the award of a Nobel prize. At the same time smaller linear electron accelerators were constructed and tested for medical purposes. Models based on this research are now commercially available. At present, 30 years into the program, a 2-mile-long linear electron accelerator is being constructed on the Stanford campus with funding from the Atomic Energy Commission.

Much of the basic research on which the productivity of the Laboratory depended was supported under a joint services (Army, Navy, Air Force) contract administered by the Navy. This form of support provided a very high degree of flexibility in choice of research objectives and program administration. Since many of the most important applications resulted from research in which the original objective was of quite a different nature, the importance of research flexibility is evident. However, it is also important to note that in their conduct of the program, key personnel in the Microwave Laboratory were aware of military needs and took an active part in seeing that application was made of significant developments, even though the ideas had originated under other promptings.

Note should also be made of the extent to which the discoveries in the laboratory were exploited through participation of university people in industrial situations. The inventors of the klystron, the Varian brothers, established the firm bearing their name for the manufacture of microwave tubes. Dr. Edward Ginzton, currently chairman of the board of Varian Associates, was formerly a Professor of Electrical Engineering and Applied Physics and director of the Microwave Laboratory. Many former students after passing through the university program either started firms of their own, or participated in the exploitation and further development of microwave techniques with other firms. A new industry has been created as a result of these interactions, and this form of research spinoff is undoubtedly a highly significant form of technology utilization.

It is very important to keep in mind the time scale which is revealed by examination of the history of developments in the Microwave Laboratory. Basic and significant discoveries had been made within the first five years of the program, but at the time they were made little need existed for the technology they represented. Five years, it must also be noted, is a period of time known to try the patience of many a research sponsor eager for results. Fifteen years later, as a result of farsighted nondirective research support, very important practical applications were beginning to be achieved both in high power tubes for military use, and in development of accelerators for research use. Now, 30 years later, construction is underway on an accelerator larger and more powerful than anything of its kind; this accelerator is the culmination of a research objective conceived (and serving as a research focus) fully 30 years in the past. Short-term support directed to immediate objectives would not have served to reach such a goal.

It is not possible to view the more recent research results from the Microwave Laboratory with the same long-term perspective and hence they will not be discussed here in detail. In recent years the research emphasis has shifted from tubes to solid-state devices, and basic discoveries are continually being made. Although the development of devices based on these newer research results has not yet acquired a long history, it is reasonable to expect that similar conditions will lead to a similar history of utility. In fact, the technological interaction with the industrial community is already underway.

As a second example of the long-term development of a research program, we will examine the Radioscience Laboratory in the Department of Electrical Engineering. The principal fields of interest of this Laboratory, which is headed by Professor O. G. Villard, Jr., have been the study of the earth's ionosphere, radio propagation, radar and radio astronomy, and scientific investigation of the solar system using radio and space-probe techniques.

This is an interesting program to examine because research in the areas included in "radioscience" (radio propagation, for example) does not normally lead to the development of tangible "products" which can be manufactured and sold. Research in these areas, consequently, is largely undertaken by universities and government laboratories. Thus the demonstrated impact of this program on the industrial and government communities (including activities within the NASA sphere) is of particular interest.

Significant research in radioscience had not been undertaken at Stanford prior to the end of World War II, although a small program of ionospheric data acquisition for the National Bureau of Standards existed during the war. After the war the research started in a small way with separate programs in very low frequency pulse sounding of the ionosphere, and with the study of radio reflections from the ionized trails left by meteors.

The primary focus of the Radioscience Laboratory effort has been the scientific investigation of phenomena in the earth's ionosphere and beyond by the use of radio techniques. Nonetheless, because the program started with flexible support which allowed pursuit of research goals wherever they led, the later activities of the program have been quite diverse, and have resulted in important practical developments. Research in meteor echoes began at Stanford in 1946. During the first five years the results related primarily to the original topic; in the process of attempting to understand the received signals, new techniques were discovered for measuring wind velocities, meteor speeds, and parameters of the ionization process. Near the end of the first five years of study other lines of research began to open up as a direct outgrowth of the investigation of related phenomena. From a study of interfering echoes seen when attempting to record meteor signals it was found possible to measure radio propagation conditions over a wide geographical location using a single sounding station. A development of this technique was widely used in the International Geophysical Year. A further refinement of this "scatter-sounding" technique has been applied to existing shortwave communications circuits to determine the state of propagation conditions, and the optimum frequencies for use at any given time. Along another line, application of large antenna arrays constructed for study of echoes from very small meteors made possible the reception of the first radar returns from the sun. An extension of the program in this direction has involved study of the interplanetary plasma using echoes first from the moon, and more recently, signals from space vehicles.

Experimental modifications to the Mariner Mars mission to permit occultation studies of the Martian atmosphere have been a further outgrowth of this branching of the original study. Again, availability of a component of flexible research support made possible a quick response to the first Sputnik launch using existing radioscience facilities. Continued research along these lines has led to important measurements of ionospheric properties by satellite radio experiments.*

The other original branch of the Radioscience Laboratory program consisted of the very low frequency pulse soundings of the ionosphere which were started by Professor Robert A. Helliwell shortly after World War II. After the low-frequency sounding program had been underway quite productively for about five years, a new line of research opened up in an interesting way. The low-frequency signals had been produced using a transmitter which created an electromagnetic signal somewhat similar to that produced by a lightning discharge, and an alternative way of studying low-frequency reflections had been developed whereby natural thunderstorm signals were

*As an outgrowth of the interest in space challenges resulting from this work, selection of a Radioscience Laboratory professor as a Scientist-Astronaut trainee for the Apollo program was recently announced.

used in place of the man-made signals. However, in listening to the echoes of the lightning-caused signals from the ionosphere, other signals lasting about a second and sounding like a declining whistle were heard. This new and intriguing line of research was followed up, and it was proved that these signals--called whistlers--were transmitted along lines of the earth's magnetic field to heights of several earth radii before coming down in the opposite hemisphere and being reflected back along the same path. Pursuit of this topic has resulted in very exciting and productive studies in magnetospheric physics. A worldwide network of whistler observing stations was established in the IGY, and more recently the studies have been extended by use of receivers in the magnetospheric medium with NASA support.

It is worth noting again that the most useful applications of these new research studies did not arise for a considerable number of years after the commencement of the programs, and that the scientific output, as well as the development of other useful applications, is growing although the basic program is 20 years old. The important application of meteor reflection knowledge to the development of meteor-burst communication as a fundamentally new propagation mechanism occurred 10 years after the first Stanford interest in the field. More recently, important defense applications of a classified nature have taken place as a direct outgrowth of the earlier program interest, and have been publicly cited by President Johnson as being of high importance to the nation's defense posture.

Although the Radioscience Laboratory efforts have been largely directed to study of basic scientific phenomena in space and the ionosphere, industrial spinoff has occurred as well. To give but one example, Professor Allen M. Peterson of the Radioscience Laboratory, who was instrumental in the development of ionospheric sounding techniques at the University, was also a cofounder of Granger Associates, a local firm noted for its ionospheric sounding equipment.

Here it may also be mentioned that the Radioscience Laboratory has maintained a close relationship with the Stanford Research Institute as one means of insuring that new research results would influence the solution of practical problems. This relationship is especially close because of several cooperative arrangements in addition to consulting or subcontracting. Professor Peterson of the university Radioscience faculty holds a joint appointment as Director of the laboratories at SRI dealing with problems of radiophysics and radio propagation. Further cooperation was ensured by the formation of the Stanford Center for Radar Astronomy for the joint conduct of research by the University and the Institute.

Because of the global nature of radio propagation and space research, the Radioscience Laboratory is in contact with other organizations and research facilities throughout the world. This contact is maintained in many ways, including relations with former students. An excellent example is the connection between the Radioscience Laboratory and the program of the Brazilian National Commission on Space Activities (CNAE). The Scientific Director of the CNAE, Dr. F. de Mendonca, came to Stanford in 1958 and obtained his Ph.D. degree working on satellite studies of the ionosphere. Three additional students are expected at Stanford from the CNAE within the next few months.

The two cases just reviewed related to broad laboratory programs. Much smaller program components also furnish examples. Thus, 10 years ago a research group in a third Stanford laboratory developed and demonstrated some unique techniques of particular use in electronic warfare. Although there was no immediate "product," later military procurements of related industrial developments in this area have been in excess of $100 millon. The Stanford group was in direct touch with five industrial organizations in connection with the transfer of technical information out of the Stanford program. It is perhaps significant that two-thirds of the original Stanford group are now in industry, four as presidents of companies.

What constitutes the "product" of university research? Too often it is presumed (by universities and outsiders alike) to be research reports and technical presentations at scientific meetings. These may serve as effective communication media with other research groups. They usually do not serve to excite industrial interest or to contribute to the direct transfer of technical information to industrial groups. Industrial visitors are often disappointed in not finding a tangible product which they can exploit directly in their programs. It is unlikely, too, that the industrial visitor will successfully excite the interest of a busy university researcher in a knotty problem that falls outside the researcher's immediate sphere of activity. The pattern of profitable interaction with the outside community is many-faceted. It develops only through conscious effort in many directions.

Experience has been gained at Stanford with a number of mechanisms for promoting relations between a university and outside groups. Although the forms of interactions to be discussed now have, for the most part, been consciously organized by the university, the actual contacts occur between individuals. The formalized procedures are effective insofar as they result in increased individual interactions.

One of the most significant of the university-organized activities is the Honors Cooperative Program in the School of Engineering. Under the auspices of this program, employees from more than 30 companies in the area from San Bruno to San Jose receive full-time compensation for their work with their firms, but are released from work to attend regular classes at the university on a part-time basis. At present, over 600 students are attending regular daytime university classes under this program, and the group from the NASA Ames Research Center is one of the two largest. Selection standards are high, as it is considered an honors program, and all participants must be candidates for advanced degrees. Doctoral candidates are required to spend, in addition, one full-time academic year at the university.

The program has been mutually very beneficial. The opportunity to offer continuing education to their employees is a key recruiting point with the area firms and is also important in maintaining staff competence. The university gains not only from a component of mature and motivated students, but from the large number of personal contacts that develop between the university people and the personnel of the outside organizations. Many of the research results and new techniques developed in the university through research are carried to organizations where they can be applied by way of this student-employee interface. The arrangements between the university and the cooperating firms also provide for payments to the university to help defray the full cost of education. In this way, the program is able to function without imposing an additional financial burden on the school.

A program of special pertinence to Stanford's participation in education for the space effort is the joint University-Ames Research Center part in the ASEE-NASA Summer Faculty Institutes. This program is sponsored by the American Society for Engineering Education through its Space Engineering Committee; it allows selected engineering and science educators to engage in research in a NASA laboratory for a period of 10 weeks while at the same time attending advanced courses and seminars related to the research. The Faculty Fellows, who are the beneficiaries of the program, are predominantly young teachers from colleges and universities with small graduate-study programs in space-oriented fields and with limited research opportunities in areas of major importance to NASA. The Centers select the research topics and assign an advisor to each Fellow; the universities organize and teach the special courses and seminars, and provide the general administration of the Institute. Financing is provided by NASA. At Ames and Stanford, the Institute program concentrates on the fields of space physics and plasma dynamics, thermo- and gas-dynamics, guidance and control, and the life sciences. In the summer of 1965, there will be 24 Faculty Fellows in the Ames-Stanford program.

The Faculty Institute program has been a success not only in widening the range of contact of faculty from smaller schools, but also in terms of increasing the cooperation and recognition of mutual interests between the cooperating Center and University. As an example of the way in which contacts of this sort tend to develop, we note that the Professor in charge of administration of the Summer Institute program at Stanford is now involved in developing a new biomechanics-life sciences internship program. An interesting aspect of this exploration is that this university interest in biomechanics is centered in the Department of Aeronautics and Astronautics, and among faculty in this area with a background in mechanics and structures there is now arising an exciting awarness of interdisciplinary problems in the structural mechanics of blood vessels and the nature of fluid flow in elastic pipes (inspired again by the flow of blood).

Another form of university-industrial-government laboratory interaction at Stanford arose as an outgrowth of the reporting of research results to the Department of Defense Technical Advisory Committee (TAC) which oversees the Joint Services Program in electronics (explored in more detail in Part

V and Appendix E). For many years the Stanford Electronics Laboratories have held a two-day annual meeting during which technical papers, exhibits, displays, and tours are arranged to illustrate recent research results thought to have particular significance. During an almost 20-year history, attendance at this review has grown from a very few visitors to well over a hundred representatives from various government sponsoring agencies and laboratories. For the past 10 years (and at the request of our government sponsors) a repeat of the review has been held for representatives of industrial contractors invited by the government sponsors. This second 2-day session has also grown in popularity, with attendance in excess of 250 industrial people in recent years. These meetings have proven to be an efficient and popular way of acquainting the industrial and government communities with the University program. Their value lies not so much in the immediate transfer of detailed research results as in the establishment of contacts whereby further explorations in depth can be made as the promise of a match of interests suggests.

Sharing some common elements with the TAC and Contractors meetings are the Industrial Affiliates Programs. There are three such programs, one in Solid-State Electronics, one in Aeronautics and Astronautics, and the third in the Construction Institute. The first two are in areas of particular interest to NASA and involve over 20 industrial organizations. The Affiliates assist the university financially, and in turn are given a special opportunity to keep in contact with research and graduate-student activity. In the Solid-State program, a 2-day presentation of research results is made by faculty and graduate students annually for the benefit of the Affiliates, and in turn talks on current industrial activities are given by one or more of the Affiliates. Follow-up visits to the industrial organizations are also a part of the arrangement. Many of the most significant university-community contacts arise from individual action. Examples of particular relevance to the space program are the joint seminars held by Ames and the university's Plasma Institute and a recent conference on the Solar Wind sponsored jointly by Ames and the Aeronautics and Astronautics Department of the school.

Courses are frequently taught in special areas at the university by qualified lecturers from outside institutions. In electrical engineering, courses have been taught recently by employees of SRI, Lockheed, Sylvania, United Technology Laboratories, Philco, and NASA-Ames; in Aeronautics and Astronautics alone five members of the Ames staff have taught courses in 1965, and others have given special lectures.

From the point of view of encouraging close industrial-university relations, the establishment of an industrial park by the University in 1950 was a very significant milestone. Choice research-building sites on university land near the central campus* were made available on long-term leases, with the University exercising strict architectural control. The attractive research environment that resulted has been very important in promoting close industrial contact and participation in other aspects of the university program.

The presence of a research park in close proximity to a university is sometimes taken as evidence of a successful university-community relationship. It is interesting to examine this contention in view of the notable lack of success of many research parks--a phenomenon that has been the subject of a number of recent studies. R. G. Snider has reported (Industrial Research, January 1965) that only 50 percent of 78 research parks investigated were considered "successful," even using the rather undemanding criterion for "success" that the park have more than one tenant. (Twenty-eight had no tenants.) Many unsuccessful parks were located near educational centers, from which it is obvious that beneficial interaction does not occur automatically. (However, the data show such proximity to enhance the chances for a successful development.) It is perhaps most significant that 82 percent of the "very successful" parks (more than three tenants) established prior to 1962 are located near universities judged by Snider to be particularly strong in research and engineering.

The purpose of this section has been to review aspects of the history of long-term research-program development at Stanford with a view to exposing those elements which have been important to fallout of important practical results. We have stressed the long time scale from concept to

*The availability of such undeveloped land was a particularly fortunate University asset.

full application of new results, the need for flexibility in program guidance and funding, the necessity of faculty interest in and recognition of useful research applications, and the need for a research focus. We have also explored some of the mechanisms which the university has found to be important in helping to stimulate their relations with the technical community and the applications of the results of University research.

The examples cited are among those that have been considered successful. Other universities have had comparable experiences, though the patterns may well differ in detail. In any case, the necessity for active and planned university participation outside its borders and for maintenance of a mind-set favorable to interaction, cannot be overemphasized.

One of NASA's serious concerns is that practical utilization be made of developments from the space program. We have no doubt that such applications will arise on a very large scale, but point out that the program of the space agency is still quite new. The development of applications and fallout can be expected to build up with a time scale comparable to that typical of the research of other agencies. If maximum utilization of university research is to occur, it is vitally necessary to foster an environment of interaction of the type that has been discussed, as well as to constantly seek new forms of interaction. The actions and attitudes of the sponsoring agencies have a major influence on success.

The impact of space research in the long run will much more likely be the development of new industries to exploit major innovations than merely the dissemination and application of isolated techniques. While every effort should be made to take advantage of such isolated technical innovations and to make them more widely available, the responsibility of universities with respect to research exploitation cannot be limited to such a narrow view. Programs of the nature of those discussed in this section are effective in making known isolated innovations in technique, but the greater gain arises from development of whole new fields of technology and of the industrial base to exploit it. The major university responsibility is to be aware of and interested in promoting these larger goals.

students, a university should be an enclave, a source of freedom. They are concerned that if the university is "bought," and identifies itself with the solution of existing social, political or military objectives, it will fail in its unique role as a leader and critic of the status quo. Yet many students recognize that at least in engineering the results of responsiveness to society's needs have served to give a focus to creative work of the faculty that has been both productive and satisfying. Moreover, the position of the critic within the system is often stronger and more influential than that of the outside critic, even if more constrained.

Thus, many students see a logical connection between a university's needs for independence and its responsibility to serve the society which supports them. The editorial page of Stanford's daily student newspaper can be used to illustrate these attitudes. From the paper the morning these words were written, we find the following rather flowery statement:

> "...It should rather give us a certain sense of pride that American universities, and Stanford not the least among these--have come to recognize that their role is not merely to preserve and promote what is best in our society but also to criticize and condemn that which is worst."

and

> "Now, in this springtime, the 'exploding outside world' has touched us at last. And we it. And Stanford, one hopes, will not soon or easily return to the 'somewhat warm and protective cocoon' that has been our home for all too long."

Although service and involvement in society is viewed critically by some, the stronger motivation appears to be participation, but with independence and freedom of direction. A major student need, generally felt in engineering, is greater and earlier direct involvement with real-world engineering problems. The context of the above newspaper quotation was civil rights, but in engineering, there is a corresponding desire to deal with real problems and to gain the satisfaction of applying theoretical and analytical techniques to the general good.

The most common and detailed complaints of students interviewed in this study may be classified under the heading "communications." They very frequently feel themselves to be isolated, and they wish they weren't. A few students are sufficiently mature and aggressive to

E. THE STUDENT VIEWPOINT

In considering the relationship between the goals of NASA, of the universities, and of the surrounding technological community, it is important to understand the needs, goals, and problems of each of these groups. To lay a groundwork for the better understanding of the role and responsibilities of the university in engineering, and especially in its relations with NASA, this section and the one to follow will explore the views and activities of students and faculty within the Stanford School of Engineering. It will be shown that student and faculty attitudes and problems have an important influence on the appropriate forms of university research organization and support.

University students are intelligent, literate, and friendly critics of a university's strengths and weaknesses. Interviews with students concerning engineering-school problems have shown the students to have clearly delineated reactions to important aspects of the functions of the university. We report these views without editorial comment; the fact that they exist is important regardless of their degree of validity.

The majority of student concerns can be placed in one of two categories--those relating to goals, and those relating to communications. Despite their criticisms, most of the students interviewed at Stanford are pleased with their education and appear to adapt well to the system which supplies it. Many claim no major complaints, but they nonetheless have many comments to make. In engineering, most students have not yet had the opportunity to become closely associated with practical engineering programs and are still speculating about their individual roles in the scheme of things.

Students are idealistic. They are among the strongest supporters of the ideals of academic freedom and of service to society. However, students are very much individuals and they differ greatly in their interests, needs, maturity, background, and viewpoints. Some feel it particularly important for a university to remain "uncommitted," and are very wary of a subtle influence which they associate with outside financial support of research. Some believe such support has exerted undesirable pressures on university growth and commitment. To these overcome the barriers that hold most back. A few recognize that the initiative is theirs to contact faculty socially as well as at school, to poke their noses into research laboratories, or to follow programs of their own devising. Many, however, do not. One student stated "I pay $470 tuition, and yet I feel as if I have to teach myself."

More frequent student-faculty contact is one of the chief student desires. More contact is sought not primarily in the office or classroom, but informally. Usually students feel they will be welcomed by a faculty member to discuss a particular specific question. However, engineering students generally feel that the faculty is not easily contacted informally in situations where there is no agenda, nor communicated with in discussions touching on topics yielding overall perspective, or opinions, philosophies, background. Students feel somewhat rejected, left out.

Faculty availability depends strongly on the habits and commitments of the professor concerned. It seems apparent that the heavy demands on faculty time of the combined effects of formal classroom teaching, research, and other professional activities place a severe drain on the resources of most faculty members. In arranging interviews for the purposes of the present study, faculty schedules rarely allowed time for discussions within less than three or four days, and often because of travel or other conflicts, weeks or more were required to make appointments. (Deans and department heads are easier to contact than many of the faculty.)

In the face of this hectic atmosphere, it is not surprising that many students feel rejected. One first-year graduate student on a research project reported seeing his research advisor but once in six months. Most faculty are available to their students regularly for such purposes, and some are notably easy to contact. But again, a student commented that in all the courses he had taken in engineering at Stanford, only two professors had learned his name (and one of the two is a department head).

Many students do not feel that the spark of excitement from research programs often reaches the classroom, or even that research results are apparent in the lecture content. However, there are exceptional courses where the content arises directly from research, and in these courses students experience a sense of involvement. They report that some of the best teachers are heavily involved in research, and they see little correlation between research commitment and classroom effectiveness. They consider most instructors dry.

Since the press of scheduled work takes such a toll of faculty time, it would appear that additional planning must go into ways to make faculty-student contact of an informal sort more likely. The faculty tend to disappear into the environment of the sponsored research activities between lectures. The argument is sometimes made that a responsibility rests on the research sponsors to help alleviate the situation. The policies of the Government in connection with facilities grants are influential. The rules concerning use of federal funds from research agencies for the construction of facilities are very strict, and encourage maximum utilization for research laboratory and clearly associated office space. Libraries, classrooms, study areas, lounges and the like are generally prohibited. Thus a university facility designed according to these restrictions is apt to become a research fortress having no locations for students to congregate. Students not on research projects are effectively isolated from the faculty. Additional facilities for students can be provided from independent university funds, but inspection of existing facilities shows this does not always occur. It might be well for such sponsoring agencies as NASA to encourage rather pointedly integration of NASA research facilities with other university functions in ways that would promote faculty-student contacts. The primary responsibility in this regard, however, resides within the universities.

Faculty-student contacts are not the only areas of student concern. Student-student contact in engineering is also deficient in many cases. Many students appear to follow the example of the faculty and spend much of their time behind closed doors. Many express a preference for an educational system allowing more room for both group activity and for individual initiative, for following one's own nose. Innovations in teaching which provide such opportunities are very popular. The Space

System Design course, the use of case studies, and the internship program in Engineering-Economic Systems which are successful examples from Stanford are described in Sec. IV-B and the Appendices.

With the principal exception of the part-time Honors Cooperative Program students (who attend school while employed by local industry), most Stanford students have a rather sketchy idea as to what engineering practice is like, and of the agencies which support it. For instance, one student projected that "most students view NASA as just a bunch of scientists, with probably little concern for universities." The very real concern of NASA for effective and productive university relations is not apparent to many students, and their knowledge of other aspects of the space program may be but little deeper.

Student views are not primarily negative, despite the emphasis given above to certain areas of concern. Research in space is of special interest to students because, unlike military research, the goal is clearly idealistic. Moreover, almost every area of engineering research is touched by the space program. To the extent that space research activities are broadly disseminated through the engineering discipline, the objectives of the NASA program can serve as a unifying influence, providing motivation to a large portion of the student body and serving to bridge artificial barriers between departments.

F. THE FACULTY--ACTIVITIES AND OPINIONS

The faculty and students together compose the heart of a university. The attitudes, activities, problems, and goals of the faculty have an especially important influence on the character of a school. In this section we shall review the scope of the activities of the engineering faculty at Stanford, and then consider their attitude toward the research environment. Such a review will be helpful in assessing the success of the present form of research organization, and as a basis for suggested changes. The emphasis will be on areas of concern rather than those of satisfaction. The points of view expressed derive from the faculty and reflect feelings as well as objective fact.

The quantitative conclusions presented are based on information obtained from probing interviews with 34 Stanford Engineering School faculty members deeply involved in the research program. Seventeen of these professors were receiving research funding from NASA, and the remainder, with one exception, were funded by other government agencies. Twelve divisions or departments of the Engineering School are represented in the sample. The formal interviews were augmented by less-structured discussions with many additional faculty members, and opinions and expressions of interest were solicited from substantially all of the faculty (140 individuals).

1. Faculty Schedules and Interactions

An engineering professor is typically a very busy man. At Stanford perhaps 25 to 50 percent of his time is employed in teaching one or two courses each term. If he lectures five hours per week, another ten are needed for preparation, and not infrequently substantial efforts go into organizing written text material, revising course content, and the like. Another 25 percent of his time may be allotted to other nonresearch activities supported by the academic budget. Included during these hours are service on department, school, and university committees, advising students, giving qualifying and university oral examinations, and considering applications for admission to graduate study. Also included is time spent on other professional activities such as editing professional society journals, entertaining academic visitors, and reading theses.

The remaining 25 to 50 percent of the week is devoted to research. However, much of this "research" time is consumed in such activities as contract procurement, budgeting, report writing, selecting and supervising assistants, attending administrative committee meetings, preparing talks, traveling, and meeting with research visitors. What little remains for the key items of study, individual research, and exploring new ideas is generally obtained only by exceeding the nominal limits of the working day. The expanded week may include up to one day consulting with nearby industrial firms (which at Stanford is additional to the normal university time commitment), and service on outside government and professional society committees.

One evident characteristic of the engineering faculty members involved in research is a high degree of involvement with outside institutions on a working level. The faculty was asked to name the industrial, university, government, and nonprofit research institutions with which they had active working contacts. Among faculty working on NASA-supported research projects, 93 percent had working arrangements with industrial concerns, either on the basis of cooperative research, consulting, subcontracting, or otherwise. The median number of firms with whom each faculty member was in contact was over three. In the NASA-supported group, 53 percent had close contact with a median of two other universities, 68 percent had close contact with a median of two government research laboratories, and about 30 percent were in contact with a nonprofit laboratory such as SRI. In contrast, among the faculty having research support from non-NASA agencies, only 52, rather than 93, percent had working arrangements with industrial laboratories, and 33 percent rather than 68 percent worked closely with government groups. The degree of involvement with universities and nonprofit groups was unrelated to the source of support, as was the average number of contacts of each type among those faculty having a particular type of contact. The average total number of contacts per faculty member was 5.9 for professors with NASA support and 3.7 for those without.

It thus appears that one of the characteristics of NASA support of engineering research at Stanford is that it has been most actively sought by faculty with the greatest involvement with industrial and governmental laboratories. Examination of particular programs with especially high NASA components confirms the statistics, and shows in addition a strong tendency for the development of contacts on an international as well as a national basis. Working arrangements may be cited with the Brazilian Space Administration; the University of Kyoto, Japan; the C.N.E.T., France; the C.S.I.R.O., Australia; the D.S.I.R., New Zealand, to cite but a few, together with the conduct of experiments in the arctic, antarctic, in Santiago, Chile, on the Great Whale River, Hudson Bay, and in many other parts of the world. These wide contacts reflect the world-wide character of space experiments.

Within the University, 23 percent of the faculty members with whom the engineering research groups have close contact are in other departments. This figure is independent of the source of the research support. The average number of other faculty members with whom members of the School are in regular contact is just over 4.

Faculty with NASA grants supervise a median of 6.5 graduate-degree students each, in contrast to a median of 4 for the interviewed faculty members with other agency support. All Stanford engineering faculty members teach regular classroom courses; there are no research professors. The average class size and number of hours taught are identical for the NASA-supported and the control group. We conclude that the NASA engineering research program at Stanford has not divorced the associated research-minded faculty from graduate-student training and classroom teaching.

2. Faculty Responsibilities for Research Support

In engineering at Stanford the predominant form of research support is by project. The faculty member active in research typically procures his own project funds (including the research portion of his salary) by directly contacting a sponsoring government agency. A very minor amount of support comes from industrial sources, and a very little, relatively, is administered in block form by the Engineering School. As regards the engineering faculty as a whole, 15 percent are totally supported salary-wise by the academic budget; the remainder receive some salary support from sponsored research. Sixty-five percent of the faculty are "principal investigators" on one or more contracts and/or grants. The remainder of the research participants are associated with them in on-going programs.

Because the faculty member is often largely on his own in fund procurement and project continuity, the group of research-oriented faculty interviewed were participating in an average of 2.8 coexisting contracts or grants each from an average of 2.7 funding agencies. As shown in Fig. II-1, the most common number of grants per faculty man was three, with two or four the next most common. The most frequent number of sponsoring agencies was three or four. Such a diverse source

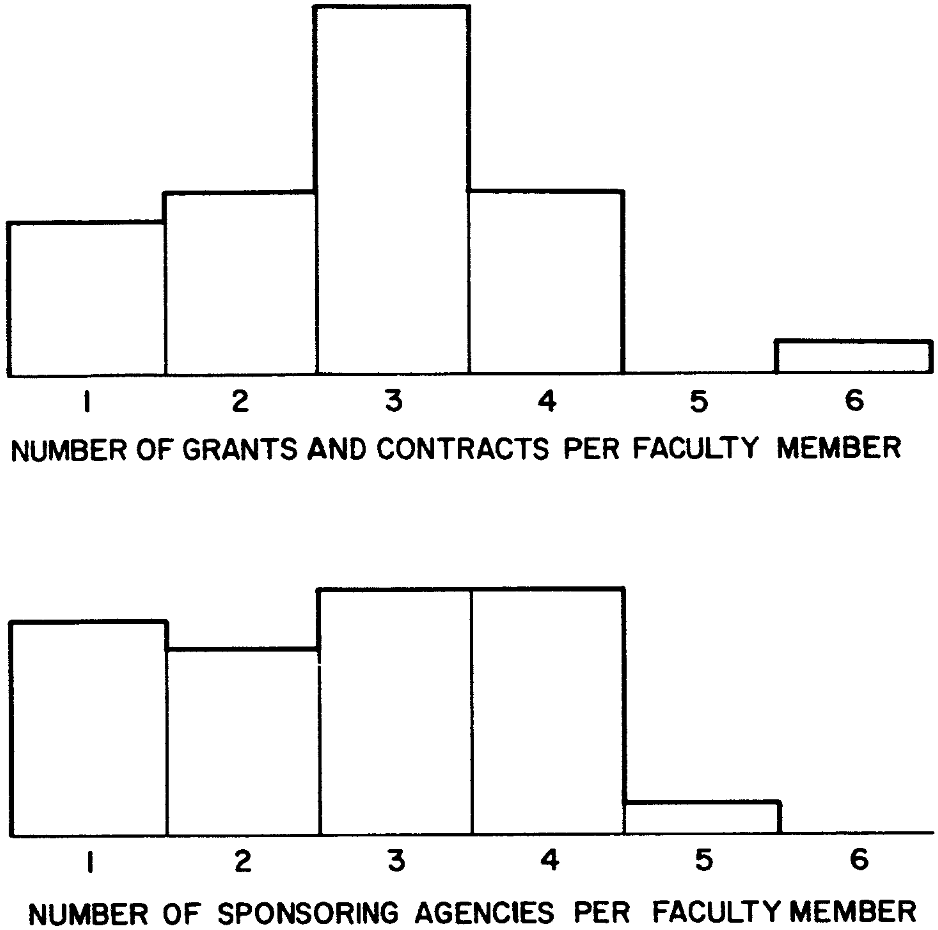

FIG. II-1. DISTRIBUTION OF THE NUMBER OF GRANTS OR CONTRACTS, AND OF THE NUMBER OF SPONSORING AGENCIES SUPPORTING FACULTY MEMBERS ACTIVE IN RESEARCH.

of funding is considered by many faculty members as important insurance against sudden cutbacks in support. With an average of 5 graduate students dependent on project support during a Ph.D. program of typically four years, maintenance of adequate funding is viewed as a serious faculty responsibility.

The multiplicity of projects, and their frequently short duration, poses other serious problems to the faculty. In some cases the nature of research undertaken is influenced by the need to be able to report significant results quickly. There is an occasional problem in determining which projects should properly report which new research result. The multiplicity of projects, each with its stated objective, may also tend to diffuse the research effort best concentrated in specific currently promising lines. On the other hand, since a relatively large number of independent student thesis projects must be financed by most faculty, diversity of support is often appropriate to the diversity of activities of the students. One notable effect of the need to find several sources of support to fund a continuous, coherent program is that programs below a certain critical size are difficult to maintain.

Those faculty of a more contemplative disposition who do not adapt well to the administrative requirements of a large research group, or to the demands of agency consciousness, or who specialize in research areas difficult to fund, tend to exist in a relatively precarious state. Such faculty often spend a lot of time worrying, and some of their division or department heads also speak of living in terror of project termination. (The step-funded NASA grants are a great help to those who have them, as are other longer term support arrangements.)

The ease with which faculty members secure support is highly variable. The relevant factors include field of specialization, personality and reputation of faculty member, and the method of approach. For the sampled faculty members, it was found with good correlation that for each $5,000 of yearly research support, about one day of promotional activity was required. At first sight this appears to be a pretty good return. However, for large research programs, the time needed to generate and administer funds becomes significant. For a $200,000 per-year program, an average of 40 days are devoted to promotion, administration, and follow-up. These days come not out of the 250 working days in a year, nor out of the 125 research days, but out of the much smaller number of days left over after routine project tasks are handled. These peripheral efforts constitute a very significant drain on prime, free creative time. For a program of about $600,000 the project leader must spend virtually full research time in these associated activities. When a project assumes these proportions, however, it usually becomes feasible to delegate much of such work to research associates. Smaller programs don't permit much delegation.

A few faculty members with exceptional reputations, or working in particularly favored fields, find that opportunities for research support come to them without direct solicitation. This faculty group, however, typically exhibits the personality traits characteristic of the better research recruiters. They show an awareness of the need to work closely with individuals at the sponsoring institutions, and they agree on the necessity of personal contact to supplement formal submission of a proposal. Even so, most faculty, including many of the successful "salesmen," develop only a very limited view of the agencies with which they work. They locate a few key contacts and often express little desire to see more of the agencies. In view of the limitations on faculty time, this restricted view is not surprising.

The funds needed to support a research program increase rapidly with the number of students involved. From study of supported Stanford engineering-school projects, it has been found that as a minimum, about $6,000 per graduate student is required per year. However, as shown in Fig. II-2, perhaps only one project out of five operates near this level. On the average, the annual support needed is about $6000N^{1.7}$ dollars per year, if N is the number of students. One project out of four requires $3000N^{3}$ dollars per year. It may appear that the smaller projects are more efficient in producing graduate education in terms of financial expenditure. However, these data are affected by the fact that the larger programs are often in fields requiring more expensive items of experimental equipment, or full-time nonstudent assistants, and project amounts may include maintenance of remote field sites or acquisition of major subcontracted items and special research facilities. The more expensive programs may be equally efficient in the conduct of a broader type of research. In some areas of engineering, research funds are difficult to obtain, and in these areas students are found working on projects without outside funds.

3. Attitudes toward Funds Recruitment

Although recognizing that the growth of the School of Engineering has been possible only through use of outside contract and grant funding

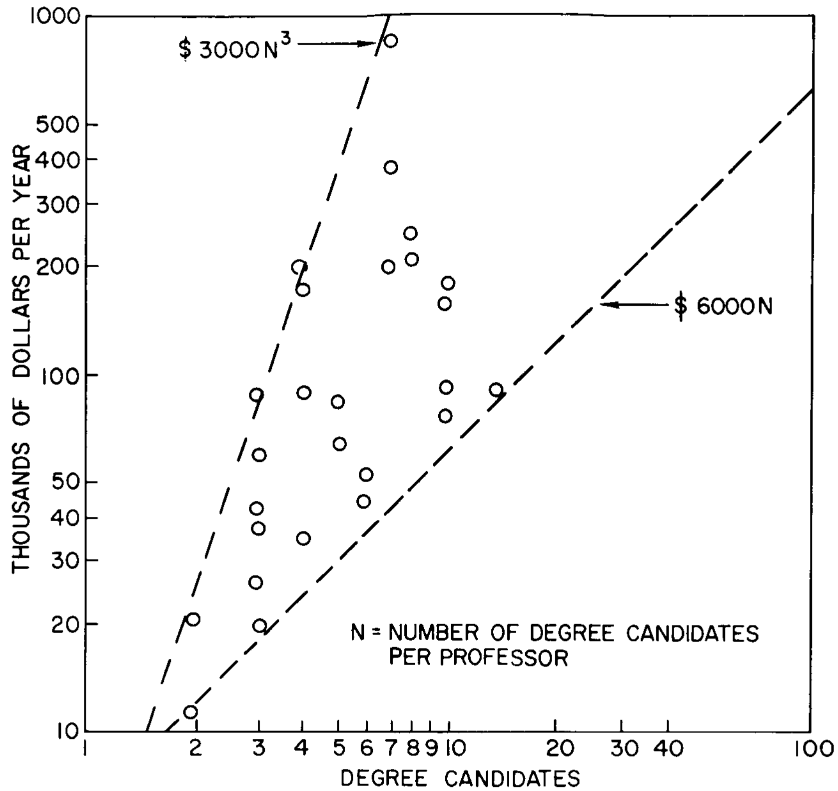

FIG. II-2. RELATION BETWEEN DOLLAR AMOUNT OF FACULTY RESEARCH PROGRAMS AND NUMBER OF DEGREE CANDIDATES SUPPORTED.

of research, and aware that university funds to cover full research salaries of faculty, students, and staff simply do not otherwise exist, many faculty members are distinctly unhappy with the arrangement. The objections range from distaste for "having to go out and recruit my own salary" to a feeling of restriction and lack of full freedom to spend time in those ways deemed most profitable. For example, one faculty member said he had pretty thoroughly exploited the area in which he had been working for a number of years and wished to spend some time simply studying and getting started in a new area. He felt that he was constrained, by the necessity to maintain salary support, to a continuing allotment of his time to projects in a more familiar area.

In contrast, a number of faculty suggested that there are real advantages to relating faculty salaries to project procurement. These members feel that the faculty is thus kept on its toes, and is motivated toward the submission of proposals and development of new programs. In addition, it was pointed out that under the existing circumstances of project funding the faculty do find time for such activities as writing books and, not altogether infrequently do go into new lines of research. The project vs block-grant question is explored further in later paragraphs.

Although arranging for project financing is an individual faculty responsibility, the School provides mechanical assistance in proposal preparation. Advice regarding format is available, as is guidance regarding possible interests of outside agencies. All proposals are reviewed by the Dean's Office (and sometimes by Departments) to assure conformity with the academic aims of the school, to establish availability of research facilities and support services, to reconcile budget details, etc. Only with such approval does the University accept the proposal for formal submission. But the school has no professional research salesmen or proposal writers. In this sense, the faculty bypasses the administration in seeking research support, and questions were asked seeking attitudes toward this pattern of autonomy.

Most of those questioned feel that the deans are friendly and helpful, and if they have an appropriate problem, they will receive willing help. On the other hand, they feel the deans are busy, and they don't want to bother them. Many of the faculty members consider the deans to have little if any idea as to what the faculty members are up to or why it may be important. Again faculty views divide depending upon personality types. One professor commented that he had been at Stanford two years and had not yet had occasion to contact the dean of engineering or of engineering research. He felt that his loyalties were more closely tied to his sponsor than to a dean or the university. To this, another young and extroverted professor replied, "It's his own fault. All he has to do is show a little initiative, and he will be welcomed." Yet another older faculty member commented that close contact did not exist, and he felt as a result that his long-range research plans were not as secure as they might be. He missed having his activities poked into, but at the same time, he felt there might be some advantage to the freedom inherent in isolation. There was a feeling among many of the faculty that greater awareness of successful performance is to be found in external contacts than within the university administrative structure.

Not unnaturally, a considerable body of the faculty hope for a substantial block of funds, subject to use at school discretion, for the purpose of divorcing faculty research salary support from particular project fortunes. (Most presumed it nonetheless necessary for faculty members to recruit support for their students, for items of experimental equipment, and for project running expenses.) It was suggested that such long-term faculty salary support, if derived from outside block funding, could be most usefully committed to faculty whose interests concentrated in certain selected program areas. This was obviously not a universal faculty attitude.

4. Institutional Grants vs Project Funding

The Stanford School of Engineering differs from many others in its heavy emphasis on individual project support. An alternative structure would involve substantial research support from blocks of more discretionary funds granted directly to the school, committed on a continuing basis, and administered by an internal university mechanism. Ideally, such grants would alleviate many of the problems generally associated with project funding. Program continuity could be assured over as long a time span as deemed appropriate, yet immediate responsiveness to new proposals and needs would also be possible. Funds could be allocated for basic laboratory facilities in proportion to long-term needs of a wide discipline, and in proportion to planned annual support. Funds would be available also for use as seed money and for starting new faculty on research. Moreover, the drain on faculty time in soliciting grants would be greatly reduced, leading to an important saving in a most precious resource. The administrative load on the sponsoring agency would be greatly reduced by cutting sharply the number of individual grants to be serviced. In view of these impressive advantages, engineering school faculty members were interviewed in some detail to determine their reactions to block funding as opposed to project funding.

In general, faculty who have been successful in meeting their funding needs through individual initiative (project funding) favor the status quo. They feel that the ability to go to any of several agencies rather than a single university committee or administrator is a source of freedom. They value the contacts they have made and feel the reviews of their proposals by their professional peers on agency review committees are more impartial and competent than the typical review they could expect within the university. They anticipate that any reviewer within the university would either be a competitor for funds or else nonexpert in their field. They cite also a possible greater flexibility in funding large projects on an individual basis, and they are concerned about the possible difficulty in arranging increases in block funding commensurate with overall growth of school activity. The large total faculty-agency contact on the project basis was cited as important in keeping the faculty aware of agency problems.

To some extent these views reflect resistance to tinkering with success. They also appear to reflect a concern with reward, and its source. Obtaining a contract from an outside agency after competitive review is a test of worth, and the resulting support is rewarding and motivating. Few faculty appear to find comparable sources of reward from contact with the university administration.

Those faculty members having difficulty in securing stable project support tended to favor interdisciplinary funding. As a group these faculty included a greater percentage with relatively cloistered outlooks. Although many of the same concerns were mentioned by them as by the more successful recruiters, there seemed to be a rather general assumption in this group that if the school had a good sized block of money, surely they would get some of it. Many had not given serious thought to the mechanics of the administration of such funds.

Regardless of primary allegiance to project or block funding of research, the faculty generally consider a combination the most desirable. Many of the faculty would suggest an optimum fraction for block funding of perhaps 50 percent of the total support, a figure higher than that suggested by the school research administration--which also favors joint funding (see Appendix E).

5. Faculty Concerns Regarding Program Structures

In response to questions concerning the nature of their most pressing need, or the area of their greatest concern in the conduct of their research programs, the faculty members participating in the survey responded as shown in Fig. II-3. For the reasons indicated earlier, financial stability (continuity, not amount) and flexibility were the most frequently expressed needs.

Next most frequently mentioned was the need for special facilities and equipment. This need appeared in several forms. Faculty with individual research grants of the order of $50,000, or less, often commented that they needed equipment costing perhaps $10,000 and could not procure the equipment from the existing grants. The difficulty (approaching impossibility), administratively, of jointly acquiring on a shared basis an expensive equipment item that would be of use on more than one grant was mentioned. Equipment needs were sometimes dominant

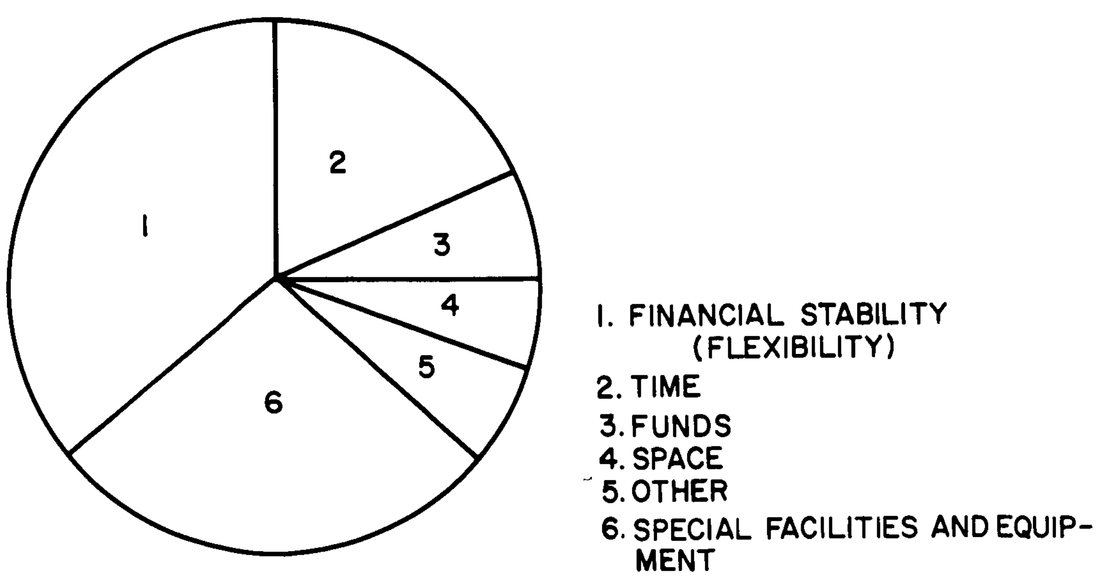

FIG. II-3. MOST STRONGLY FELT NEEDS OF FACULTY GROUP ACTIVE IN RESEARCH.

in governing the direction of the research. But some faculty who had obtained special grants for facilities found that obtaining funds for their exploitation was not comparably easy.

The third most commonly mentioned need was time. (Those faculty who did not list it as their strongest need were nonetheless often in the same tight circumstances as those who did.) The principal drains on faculty time have already been mentioned.

The relatively infrequent mention of insufficient funding for direct operating expenses or of building space as major needs reflects not the plentifulness of money nor lack of crowding, but rather an ability to adjust and become accustomed to an existing situation. Many faculty find adjustment to the uncertainty of funding <u>continuity</u> far more disturbing.

When the interview was directed to the factor or factors dominant in determining the <u>size</u> of the research programs under way, the stability-facilities-time sequence was altered. (Again, it should be emphasized in interpreting the comments to follow that the sample of the faculty interviewed included only members active in research.) Within the responding group, the replies were distributed as shown in Fig. II-4. Easily the most common answer was lack of supervisory time (or of sufficient staff to enable faculty to spread their supervision more thinly). This reply is consistent with our previous description of the busy life of a professor. In some cases, faculty felt that with more money they could afford faculty associates or professional research help to increase their effectiveness, and so some relation may exist between financing and time limitations.

The second most common limit on program size was amount of funding. This group felt that more could be done if more money were available. It is very probable that if the survey had extended to a larger fraction of the faculty, including those with more marginal support commitments, this fraction would be considerably higher. A rather small portion of the faculty felt that their program was being limited by unavailability of suitable degree candidates. Even fewer listed personal inclinations <u>per se</u> as the factor accounting for a small

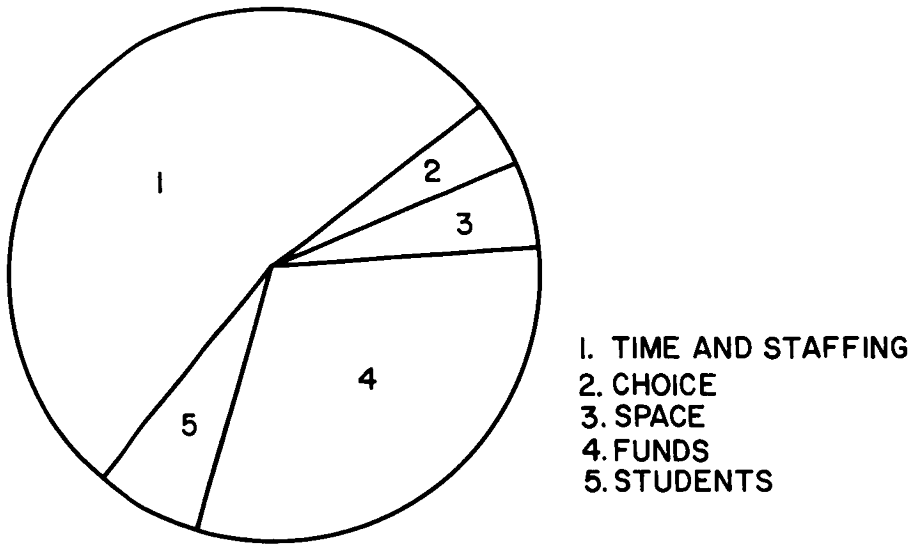

FIG. II-4. REPLIES OF FACULTY DEEPLY INVOLVED IN RESEARCH WHEN ASKED WHAT FACTORS LIMIT THEIR PROGRAM SIZE.

program size. This aspect interacts to some extent with that of lack of time; the faculty choose not to take on more than they can handle, but generally they wish that they could handle more.

The relative infrequency of the mention of laboratory or office space as a limiting factor is interesting in view of the extreme crowding of certain laboratories and with the resulting inability to expand without new facilities. As is shown in Fig. II-5, those faculty members who are not now experiencing a space problem most frequently expect the situation to get worse. Those who find facilities currently awkward or inadequate expect the situation to improve.

In the preceding paragraphs we have not dealt with technical content of the ongoing research programs. However, as the faculty look at the areas of research, and the interaction between fields, the significance of department boundaries and conventional categorizations of academic fields becomes less and less important. For instance, in the area of plasma research, applications are found in such diverse topics as MHD generation of electric power, solid-state devices, astro and planetary physics, and aerodynamics. Department boundaries serve little function in delineating research interests in such fields.

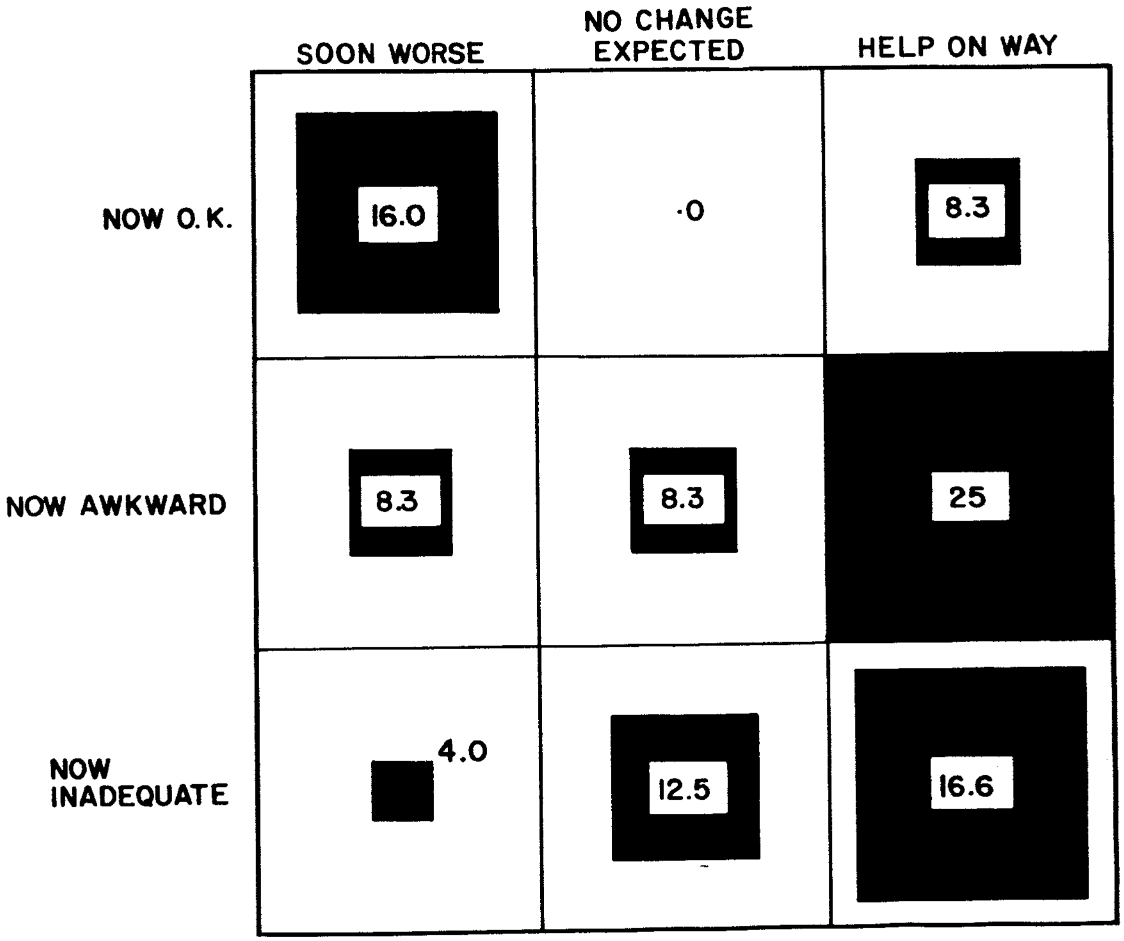

FIG. II-5. RELATION OF FACULTY EXPECTATIONS CONCERNING FUTURE AVAILABILITY OF LABORATORY AND OFFICE SPACE TO PRESENT ADEQUACY OF SPACE.

Faculty interests are becoming increasingly adaptable to multidisciplinary research objectives, and in discussing research areas with engineering faculty members, it is clear that a great deal of interest exists in relating faculty research to the larger objectives of the space program.

III. UNIVERSITY PARTICIPATION IN NASA RESEARCH AND FLIGHT PROJECTS

A. THE NATURE OF NASA SUPPORT AT UNIVERSITIES

The universities play two essential roles in the national space effort. First, they perform research of both a fundamental and a mission-oriented nature; second, they supply the trained manpower to government and industry without which a significant national program in space would not be possible. In early 1965, 140 universities were doing research for NASA, and 142 institutions in the 50 states were training students with financial help from NASA.

The Space Agency draws upon, and contributes to, the universities using two different schemes of support. The bulk of university research (about $42 million in FY 1964) was provided on a project basis in direct support of specific requirements of NASA programs. These projects are assigned to the researchers best qualified to perform the work without regard for geographical distribution or other factors not directly relevant to the forwarding of NASA's mission. However, NASA recognizes that it has a further responsibility both in meeting its longer term needs for manpower and research competence and in terms of contributing to the overall national scientific and engineering health. As a result NASA has initiated the Sustaining University Program (SUP). This program consists of a number of facets relating to training, research, and facilities. It is intended to broaden the base of space research throughout the country and in small institutions as well as large, to encourage able students to pursue an interest in space, and to assist educational institutions to act as a catalyst in the formation and development of programs that may later continue on a project basis.

The backbone of the SUP is the training grant. The 1965 training program, at a cost of $25 million, will support the predoctoral studies of over 1300 students at 142 schools located in all 50 states. The Traineeships, which are renewable up to three years, are administered by the individual institutions. In addition to stipends to the students, the program includes institutional allowances to help the schools defray the costs of instruction. The SUP also provides for the support of research; the FY 1964 amount was about $7 million.

The characteristic feature of project support under the SUP is that selection is not based purely on relevance to direct support of NASA requirements. Additionally, an attempt is made to help develop schools and researchers who are not yet established, and to further the distribution of research both geographically and at the smaller schools.

A further objective of SUP research support is the encouragement of multidisciplinary activities, and of the coordination of related projects. Thus a most important feature of the SUP is the multidisciplinary grant. At 30 universities such grants are supporting broad programs of research administered largely by the universities. Because proposals for particular programs are then reviewed internally, multidisciplinary grants make possible quick responsiveness to research ideas. They provide funds on a continuing basis that can be used to provide stability to an overall program, to support research by new and junior faculty, or to be used as seed money for the generation of new programs.

The magnitude of the research sponsored by NASA at universities is such that additional research facilities must often be provided at the universities. As a component of the SUP, NASA has (up to Spring 1965) made grants to 27 institutions to assist in the housing of space-research activities. The total amount of these grants has been $29 million, and in FY 1964 the facilities budget was about $9 million. In 1965, 11 grants are anticipated. Without such assistance, the build-up of supporting research in universities at the rate anticipated in the national space program simply would not be possible.

Associated with each facilities grant is a Memorandum of Understanding between NASA and the institution; it states as a condition for facilities support that the university accept the responsibility of seeking ways in which the benefits of the research can be applied to the social, business, and economic structure of the United States. (The practical implementation of this Memorandum by the universities has not been a simple task.)

As additional components of its training program, NASA also sponsors other activities. The Summer Undergraduate Institutes have offered 6 to 10-week programs intended to acquaint gifted undergraduate students with significant problems of space science and engineering. In 1964, institutes were held at three universities and involved a total of 135 students. In 1965 there will be six such institutes. The ASEE-NASA Faculty Institute program falls in a similar category. In this program 7 university-NASA Center combinations provided 124 younger university faculty members an opportunity for 8 to 10 weeks in research experiences at a Center while attending subject-related seminars at the cooperating universities. This program has been effective in introducing the faculty members to problems in space research, and the faculty have taken the research interests back to their schools to form the basis of an ongoing program. Also supported by NASA under the category of training are 50 foreign nationals under the NASA International Fellowship Program administered by the National Academy of Sciences.

In addition to the participation in university programs discussed above, about $2 million goes to universities in connection with satellite tracking and data acquisition, and $16 million to the Instrumentation Laboratory of M.I.T. for Apollo guidance work. About $10 million is allocated to universities for satellite instrumentation, but a large fraction of this amount is subcontracted, and does not have a proportionate effect on the universities. The total obligations to universities in FY 1964 was about $108 million, and will be about $130 million for 1965.

B. MUTUAL ADVANTAGES AND GENERAL PROBLEM AREAS IN NASA/UNIVERSITY PROGRAMS

From the university point of view, the Sustaining University Program (SUP) of NASA has been an enlightened and highly successful venture. In sections to follow we shall make further comments concerning the support of research and the funding of research facilities under the SUP.

The training grants have been successful in attracting top quality doctoral students. The principal suggestion encountered in talks with university administrators having responsibility for training grants is that it would be an administrative convenience if the NASA and NSF training grants both contained similar general administrative provisions.

opportunity to benefit from university support cutting across a considerably broader base of disciplines than the present program suggests.

Several years ago complaints were made about the relative lack of ground-based studies in fields such as radio astronomy supporting the in-space program. At present a substantial amount of work is being done on the ground and the results have been very important. For instance, the infrared mapping of Venus using the 200-in. telescope, inspired by the similar mapping made from a spacecraft, has resulted in maps of superior resolution. There remains some feeling that the extent of ground-based support of solar-system observations by astronomical techniques is not yet adequate considering the lower cost of such experiments and their high utility in hastening and broadening the scientific base of the space effort. This observation appears especially pertinent when capable astronomical or radio astronomical groups closely associated with groups dealing with flight experiments are not able to direct their attention to space-related problems because of lack of Space Agency backing.

C. PROBLEM AREAS IN UNIVERSITY PARTICIPATION IN NASA SPACE-FLIGHT PROGRAMS

While the Sustaining University Program represents the core of NASA support of universities, vital mutual benefits also accrue from university participation in actual flight programs. These are so important as to justify what may seem to be an overemphasis in this report. These values are especially present in engineering school relationships with NASA because of the effect on engineering education of faculty and student participation in broad, real-world research situations. It is in such "project-oriented" space research and technology that some major opportunities and major problem areas are encountered in NASA-University relationships.

The comments which follow are directed at those space-flight programs in which university participation can logically be anticipated, or is indeed essential. These opportunities are vitally important to the

With the growth of the SUP it appears that those components of the universities which have participated in the program so far have been primarily of two types. There have been first the space-mission-oriented groups (for instance, those studying magnetospheric characteristics) which were primed to accept any opportunity for performance of space experiments. Second, there have been researchers whose primary interest has not been tied to the space program, but who look upon NASA as another source of funds which can be used to carry on research within their normal spheres of interest. (It is interesting that, as shown in Sec. II-F, those Stanford faculty who have established research funding arrangements with NASA are considerably more active in their degree of general interaction with government and industrial laboratories than are the faculty generally. They represent the most quickly responsive segment of the Stanford community.)

However, as interest in the space objectives continues to mount, a significant phenomenon is occurring in the form of the generation of new interest in space goals among university people. Rather than seeking support for the continuation of existing interests, mission related or not, an increasing number of faculty are becoming interested in new problems which represent an interaction of existing fields with the technological and scientific needs and challenges of the space program. While this type of interaction is somewhat slower to develop than was the response which occurred as an immediate reaction to the availability of NASA support, this multidisciplinary and creative interest is especially important from a long term viewpoint.

Perhaps the major concern with respect to the SUP within the university community is that the magnitude of support may not attain as high a level as appears justifiable. The program is relatively new, and the interest in space problems within the universities has grown rapidly with the program. (As an example, the fraction of engineering-school research supported at Stanford by NASA rose by about 70 percent from 1963 to 1964, although it is still a modest fraction of the total sponsored research.) There is a momentum in the past growth to which the universities have responded, and are continuing to respond. The Space Agency has the participating schools, yet experimentation in space is a very difficult subject for graduate student participation. This conclusion was supported in many quarters. Factors contributing to the difficulty of student involvement are the very long lead times, technological and organization interface complexity, massive documentation requirements, rigorous testing and control of components and systems for reliability, procedural control by NASA headquarters and centers, competition for selection of experiments with NASA centers and industry, and the possibility of eventual booster or spacecraft or instrument failure when the program is far downstream in the time sense.

Some would conclude from the severity of these problem areas that graduate students, and hence universities, should not be involved at all (or only minimally) in NASA's project-oriented research. Our own conclusions are different. We believe a space-flight project can combine just the wide mix of ingredients, from basic science to real-world project responsibility, needed in graduate school engineering research and education. The problem areas are indeed severe, and no university group should enter into the field of space experimentation without appreciation of the difficulties. But if universities do not participate, the national space program will surely suffer in quality from the loss of the creative and imaginative talents of the university people. The loss to the universities, in terms of isolation from the most challenging and exciting adventures of our age, would be equally unfortunate.

We describe in Sec. IV-E of this report a possible program structure at an engineering school which would help alleviate some of the problem areas listed above. In the following paragraphs, we will look in greater detail at the nature of the difficulties involved in university participation in NASA space-flight project-oriented research.

1. Lead times are long, and there are many who believe they should be made longer. A graduate student may wish to be involved in all aspects of his rocket flight or balloon experiment, from conception through instrument development and flight, to data analysis and scientific deductions. However, for an orbiting vehicle (and especially for a deep space probe), the total time from conception to completion is

usually impractically long, and the chance of failure too great, for full participation by a single student. Other means of student involvement are suggested in Sec. IV-D.

While the lead-time problem cannot be banished, it might be alleviated to some degree by block payload allocations to universities and by standardization of instrument interconnections, power supply voltages, timing marks, frequencies, data readout characteristics, etc., for different spacecraft. We suggest that efforts be expanded to minimize lead time, thus reducing the danger that we will be flying payloads that represent an outmoded state of instrumentation and scientific query.

2. Universities are not well prepared to undertake the detailed, complex, and stringent documentation, reporting, and testing expected by some of the NASA field centers for preparation of university flight instruments. Even when a large part, or all, of the instrument preparation is subcontracted, the university and the principal investigator, as the responsible organization and person involved, must deal with both the field center and the industrial contractor. We fear that mounting pressures to increase even more the complexity and rigidity of these interfaces may make it impossible for universities to control their own experiments, or to participate at all in space-flight projects. Many aspects of the total space venture clearly require rigid controls. We suggest only that they be applied judiciously to avoid a net loss in effective university participation.

We consider the problem area just discussed to be the most serious in NASA-University relationships. Considerable effort by both groups is needed to ease this difficulty. From the university side, it must be recognized that high reliability is essential for spacecraft instruments, and detailed techniques and control are needed to attain this reliability. Certainly, the interplay between a scientific instrument and the spacecraft, and between several such instruments, must be considered from inception of the project to the completion of the flight. If a university professor and his team of graduate students and research workers want to participate in flight projects, they must be prepared to operate at a level of negotiation, documentation, testing, and control which is orders of magnitude more complex than they would have to cope with if they were only involved in laboratory experiments. But universities do not have the structure to match the NASA and industry organizational interfaces. The professor himself is often without an effective buffer, and must personally consider aspects of proposal "lobbying," negotiations, funding, and subcontracting, as well as details of the technical problems of specifications, parts selection, testing, reporting, instrument interfaces, ad infinitum. The reality of this situation is such that involvement in NASA projects very often reduces his effectiveness as a teacher, as a researcher, and as a supervisor of graduate students.

The professor needs help. He needs professional help at the university to provide insulation. Yet he cannot remain effective in guiding his experiment if his isolation is too complete. A remote business office, while it has its role to play, cannot provide this service. A competent, professional assistant is needed who works closely with the professor and other technical people, keeping them informed of the progress in all of these matters and consulting with them on the broad guidelines to be followed. Depending on circumstances, it may require a full-time man to provide this service for just one project. If a department or school or university has a number of NASA space-flight projects, a group of such assistants could provide this service, if they work very closely with the professors and others who are involved. Universities are often reluctant to hire people of this type--they are not found in the typical university basic research project. For more theoretically oriented work, and for most laboratory experimental work, the professor and graduate students have need for only an occasional contact with the business and outside interface aspects of their contractual work. The situation is quite different for involvement in experimentation in space, and universities must realize this if they are to participate effectively in flight programs.

We are not suggesting that universities should try to match in detail the size and complexity of the interface they may encounter in dealing with their NASA and industry partners in space-flight ventures. We do suggest that the complexity of this situation easily grows beyond reasonable bounds and that costs skyrocket as a result. Universities would be providing a very important service if they could help reverse this apparent trend.

As a result of our experience at Stanford, and from discussions with people at other universities who have participated or are participating in NASA flight projects, we see some danger of the space-science effort actually being reduced in effectiveness by certain overzealous efforts purportedly designed to make it more effective. It appears to us that the essence of this problem involves too much compartmentalization of effort and responsibility, and too few people with broad responsibilities and the competence and authority to act for the benefit of larger segments of the program.

The interface complexity discussed above may also be related to this compartmentalization. A good man, charged only with the responsibility of defining how electronic components shall be selected, for example, will be able to specify in excruciating detail the methods required to ensure the specification, handling, testing, tagging, and history-logging of reliable components. If he is not concerned about or responsible for the interaction of his specifications with such things as module or instrument vs component reliability, instrument costs, component and instrument delivery dates, compatibility with other instrument requirements, etc., these specifications may lead to insoluable situations for the experimenter. A small experimenter group may need to deal with a fairly large number of interfaces of this type, for components, magnetism, integration, power, radio frequency interference, mechanical testing, electrical testing, etc. Clearly, specifications are needed, and those involved in the narrow area of specification definition are aware that there are broader problems. Nevertheless, we see instances where costs and delays have grown to an extraordinary extent because of insufficiently broad understanding of the problems, as well as lack of communications across the boundaries encountered in this compartmentalized approach.

Perhaps the difficulty is that there are just not enough people with the required broad capabilities. If this were the central problem, it would be a clear indication that engineering schools in particular are not providing the kind and number of people needed to conduct the leading technological programs of today.

3. Another factor which may be important in the problem under discussion is the still widely held belief that the costs of the spacecraft and its instruments are insignificant or at least small compared to the booster costs. If this were true, there would be no reason to spare any effort, almost regardless of costs, to improve instrument miniaturization and reliability. However, while booster costs greatly exceeded spacecraft costs in the earliest days of the space program, the exact opposite is often true today. We suggest that acceptance of this fact has been slow, and that the current approach stressing the utmost refinement in instruments and spacecraft is not ideal when one considers the possibilities based on redundant spacecraft and larger, less than ideal, less-tested subsystems and instruments employing internal redundancy, conservative design with regard to weight and power, etc. These can be important aspects in university space experiments.

A trouble area related to compartmentalization can arise if project management by a NASA center places itself too firmly between a university experimenter team and an industrial spacecraft contractor--if the communication path becomes linear rather than triangular. Here again, it is obvious that management and control must be exercised by the responsible organization. However, there should be a clear distinction between lines of authority and channels of communications. Technical communications between an experimenter or a member of his technical team and a technical person concerned with the spacecraft structure and subsystems cannot be funneled through a third party without loss of information. It is difficult in any case for the engineers directly involved to understand each other when discussing highly complex and technical aspects of the interface between the instrument and the spacecraft. A concerted effort should be made to increase the direct exchange of information between such people and to avoid completely any aspect of control or detailed reporting until such time as such discussions lead to a suggested course of action.

There have been complaints that universities are in an unfavorable position as compared with NASA centers when both are proposing the same or similar space experiments. Our own viewpoint is that if the other problems can be at least partially solved so that universities can more effectively participate in space-flight projects, this competitive question will appear less important.

IV. THE DEVELOPMENT OF ENGINEERING SCHOOL PROGRAMS IN SPACE SCIENCE AND TECHNOLOGY

A. INTRODUCTION

Within a major university are resources of talent which relate to almost every area of NASA concern. A comparison of subjects taught in the classroom with the NASA sphere of science and technology shows that virtually no areas are overlooked. A very wide, but often unorganized, interest in the objectives and problems of the space program extends throughout many engineering schools. If mechanisms can be found to focus the latent faculty interest in NASA objectives, it appears that a valuable resource of talent and enthusiasm can be tapped for the benefit of the space program.

Although the missions toward which NASA itself is working (for example, the Apollo or Voyager programs) define the overall aim of the space effort, they do not alone or automatically provide a satisfactory focus for a major university effort because

1. The total NASA program is too vast, and an individual project too small to make the work of most individual projects seem an essential and identifiable contribution to the overall mission (flight packages would be an exception).
2. NASA is but one of a number of agencies that the faculty must consider in seeking project support--projects hence tend to be devised to be as independent as possible of the needs of any particular agency.
3. Cooperative interdisciplinary and interdepartmental projects have difficulty developing when the common thread is a single portion of the broad objectives of a distant agency.

In this chapter, we shall (in Sec. B) outline a pattern of development of engineering school interaction with the NASA program. History has shown it subject to many variations. In keeping with the nature of this study, reference is made to examples familiar to the Stanford scene. The point to be made is that there are many levels and many forms of association.

The Stanford examples have been selected to show relationships to the formalized teaching within an engineering school. This theme is explored in detail in Sec. C.

As programs expand, needs arise to coherently focus research interests. The unique opportunities NASA space-flight projects offer as focusing mechanisms are examined in Sec. D. In Sec. E some of the problems of graduate student participation in space-flight programs are discussed.

A major program will quite likely bear a strong interdisciplinary flavor, will certainly cross departmental lines within an engineering school, and may well extend across school boundaries within a university and out into the professional community. Research administration mechanisms that suffice in more traditional circumstances may well prove inadequate. There no doubt is no single optimum administrative pattern; the specific nature of the program and the normal practices of the school are important variables. There is outlined in Sec. F an administrative mechanism considered particularly suitable to schools whose backgrounds fit the Stanford pattern. Finally, in Sec. G, there are remarks emphasizing the value of a central physical facility serving a space-oriented engineering research program growing to full development.

Although we shall stress mechanisms for unifying a university approach to space problems and for drawing attention in particular to flight-project goals, the significance of isolated basic research must not be underestimated. Within any school of appreciable size there will be components of research which arise independently of any interaction with other surrounding programs. These projects may be carried on by faculty with little interest in the relation of their work to more general space goals, and yet the results of this research can be of fundamental importance. Because of the wide range of faculty personalities and interests, work of this sort can always be expected and should be no less encouraged than the more spectacular organized activities about which we shall speak at greater length. A balanced program will contain research participation representing all degrees of external involvement from pure research to specific mission-directed participation.

B. UNIVERSITY INTERACTION WITH THE SPACE PROGRAM: A PATTERN OF EVOLUTION

University programs that maintain an appropriate academic character while interacting strongly with the Nation's space program develop progressively; they cannot be ordered into sudden existence. We attempt in the following paragraphs to trace such an evolution, not because it must be followed inevitably or in all aspects but because it does represent a probable growth pattern.

This process is described in four phases. Although all phases might occur in some cases, depending on the nature and development of the engineering school, some might be skipped. However, the sequence cannot be altered in developing a coherent program as part of a major NASA-University relationship.

1. Phase I

It is possible for an engineering school without either a graduate program or sponsored research to generate an increasing awareness of the space effort. The burden is on the school; the interaction would necessarily be entirely in academic channels. The school must organize a curriculum in engineering science and technology that will provide basic support for interests in the space effort; for example, space-related case studies might be introduced at the undergraduate level. The faculty should be encouraged to examine the growing numbers of opportunities to participate in development programs such as the summer institutes sponsored by NASA-ASEE and the National Science Foundation.

Since this interaction is entirely along academic lines, the product consists of students and faculty with greater awareness and interest in the needs and goals of the space program.

2. Phase II

If a graduate program in engineering exists, it usually results in part from efforts of the school to develop faculty participation in research. For example, the school may provide encouragement and physical space for research, as well as reduced teaching loads. Possibilities then exist for organizing multidisciplinary faculty and graduate activities more closely associated with space engineering--for example, system-design courses oriented toward the space program. Cooperative arrangements with industry, built on the continuing education of industrial students, can help broaden student contacts. These interactions are most effective if student groups are not isolated, as by separate day and night schools. The NASA Traineeship Program presents a logical opportunity to establish NASA associations. Conscious attempts to bring about an interchange of faculty and industry talent have a real potential for broadening contacts with the outside community--by introducing qualified outsiders as lecturers in space-oriented courses, by encouraging outside consulting by the faculty, and by inviting outside attendance at graduate seminars (presuming the existence of conveniently located industrial and Government organizations).

This phase does not require direct NASA support of sponsored research. The interaction with NASA, again, is primarily along academic lines; the product, as in Phase I, is largely trained faculty and students--graduate and undergraduate--but with substantially expanded experiences.

3. Phase III

This phase presumes the existence of NASA-sponsored project research in basic disciplines and technologies with basic significance for the space programs. These projects are most likely to be independent, faculty-guided research efforts developed through individually generated arrangements. The transition from Phase II to Phase III occurs if capable, research-minded faculty exist. The rate of buildup of NASA-sponsored research would depend on the interests and abilities of the faculty, as individuals, to develop a match of interest with the NASA program.

Research results now join the training aspects which marked the earlier two phases as program products. There is a potential opportunity to engage in summer programs as sponsors as well as faculty participants.

Research participation in the NASA effort adds few additional administrative problems (for a given research level) and is significant in broadening faculty interests. Small schools not prepared to maintain a comprehensive multidiscipline effort may restrict their interaction with the space program to this level. However, opportunities for individuals and small groups to interact with and draw upon the facilities of a nearby NASA Center might well assist the development of a broader program.

4. Phase IV

The fullest interaction between the NASA program and a university activity of appropriate academic character will be described as Phase IV. The associations of the earlier phases may continue in expanded form. The significant addition, however, is a major, multidisciplinary NASA-sponsored research effort focused on one or more of the principal activities within the NASA sphere. This increased involvement may arise because of faculty competence and inclination evident in a buildup of NASA-sponsored project research efforts.

Both the school and NASA must assume additional responsibilities if such a major program is to be mutually beneficial. The school must be able to commit substantial resources of faculty and staff talent to the program on a long-term basis. It must be prepared to institute administrative practices not required by the less demanding and more familiar research efforts. Planned interaction with the outside scientific community must be anticipated and formalized. In turn, NASA must examine carefully the most appropriate funding mechanisms (including block funding) to assure continuity and flexibility. Needs for centralized research space and special supporting facilities--both to stimulate communication and interaction and to accommodate enlarged activities--may have to be met.

The potential products of such a program include engineers trained specifically to contribute to the NASA effort, and research results furnishing direct support to the space program and capable of serving as the source for new technologies and products of more general application.

The remainder of this chapter deals with the problems and opportunities associated with the stimulation and conduct of such major efforts.

C. FOCUSING MECHANISMS AND PROGRAM COHERENCE

The major concern in this section is with the formulation of mechanisms and the definition of goals that will, first, broaden the base of university interest in NASA programs, and second, encourage interdepartmental and cooperative studies of a type that will make possible the eventual solution of otherwise unapproachable problems.

Again, using as an example the Stanford Engineering School as it now exists, several academic programs are found which have demonstrated potential for focusing latent interest along coherent NASA-directed paths. One of particular attraction is the Space Systems Engineering Course (see Appendix B for a description of the course). As given in the 1964-65 school year, the students in this graduate course undertook the design of a Mars lander mission for the 1971 window. The students were drawn from a variety of departments in engineering, and there were representatives from the biology, philosophy, and English departments as well. Following a term of study and briefings by visiting experts from space installations about the country, they designed a system involving consideration of trajectories, propulsion, communications, biological experiments, weight, cost, and other pertinent elements. This design project was undertaken independently of the studies supported by NASA (it was financed by academic funds), and was an original and broadly based consideration of many factors pertinent to a realistic mission. Faculty from many disciplines were brought into contact with NASA problems by means of this course, and they have become aware of design, instrumentation, and scientific problems pertinent to such a mission.

A study such as this, dealing with a variety of space problems from year to year, is a very productive means for exciting both student and faculty interest in cooperative, interdisciplinary, space-related research. The course potentially could be used to define a local core around which detailed faculty-student research projects might accrete. As is most desirable at a university, such a program would intimately relate student training, research, and responsiveness to the demands of the times outside the university. At the same time, it would provide a catalytic mechanism between NASA and the individual researcher, and a meeting ground both for faculty and students within the university and for experts from NASA and industry without.

A second type of potential focusing mechanism within a university is found in organizations such as the Institute in Engineering Economic Systems (IEES). The IEES is an interdisciplinary, interdepartmental organization at Stanford developing a broad graduate research and coursework program in the area of engineering-economic systems. It has as specific objectives:

1. To develop interdisciplinary research activity in systems.
2. To establish industrial and governmental internships in the field to couple theory and practice.
3. To present system concepts derived from foundations in mathematics, physical and behavioral sciences on the one hand, and related to practical casework on the other.

The student typically spends about two years of a five-year Ph.D. program in the field (see Appendix C for fuller description). The IEES internship program has so far involved such institutions as the Federal Aviation Agency, the Bonneville Power Administration, and the Department of the Interior, as well as a small town in Peru. One of the features of the IEES program is that it creates a bridge between problems of the outside world and the teaching and research activities within the university. It involves bringing personnel from the outside organization to the university for a period of months; in addition, faculty put in time at the outside institution, usually during the summer, and often for some weeks during the remainder of the year.

The IEES program includes a very high degree of interaction across the boundaries of the school (in engineering-economic system studies, the outside world constitutes the laboratory). While this pattern of interaction is not appropriate to all disciplines, the program does open a wide avenue for contact which, because of the interdisciplinary nature of engineering-economic system studies, can bring many of the problems of NASA or other institutions to the university.

Another example exists in the program of the Design Division in the Stanford Department of Mechanical Engineering. By some definitions, engineering is always ultimately concerned with design and the function of a design division thus becomes important in all fields of engineering. (Some engineering-school activities are not engineering by this definition.) Design permeates the activities of many departments and is an essential ingredient in any complete engineering problem solution. In addition to its interest in acting as a catalyst in systems design, the Design Division has exploited the use of case studies in engineering instruction. From the present point of view case studies are of interest because of the opportunity they give to draw upon real-world situations effectively in the instructional program. (See Appendix C.)

Expansion of the case-study method to include significant examples of engineering problems and solutions from NASA centers and contractors would be an effective way of bringing both student and faculty attention to the space area. NASA could play a very useful role by making available to the universities documentation on space engineering and research activities in a form suitable for development for instructional use by the case-study method.

D. SPACE-FLIGHT PROJECTS AS A FOCAL AREA FOR ENGINEERING RESEARCH IN A GRADUATE SCHOOL OF ENGINEERING

Participation of university groups in space-flight projects can have important impacts both on supporting research and engineering and on associated academic programs. We see repeated evidence of this type of interaction at Stanford and can perhaps best explain by examples the value of such a focus in developing major NASA-University programs--the Phase IV situation in Sec. B.

In the Radioscience Laboratory (an outline of the Stanford Engineering School and research structure is given in Appendix A), several groups are concerned with satellite programs, including monitoring of topside sounder results and instrumentation for very low frequency measurements, antenna impedance determinations, and propagation measurements. Several complex plasma phenomena, which were not anticipated in the original planning of the experiments, have been found in measurements made in spacecraft. Subsequent discussions with members of another research group in the departments of Electrical Engineering and Applied Physics indicated that similar phenomena were being observed in laboratory plasma experiments, and that a theoretical investigation was under way to explain these results. A more complete understanding of both sets of measurements came about by the interaction between these two groups of research workers, and a more complete theory resulted.

In another area, a group in physics and an engineering group interested in the guidance and control art have joined forces to attack certain fundamental gravity and relativistic problems using a cryogenic gyroscope in orbit. The physics professor principally involved would probably not have pursued this interest to the experimental level without the assistance of the guidance and control group. The engineering group, on the other hand, would not otherwise be able to conduct as meaningful an experiment without this interaction, even though interested in fundamental guidance and control research associated with the actual flight tests.

It has been necessary for a local group concerned with a single experiment (the measurement of the ionosphere on Mars using Mariner spacecraft) to deal not only with the science and instrumentation for this job, but also with a wide array of other factors such as trajectories, TV look-angles, Martian magnetospheric characteristics, and propulsion injection accuracy. If all aspects of a complete satellite program were to be undertaken by a university, the potentialities for broad interactions would be great indeed.

Under the new NASA-University Satellite Program, a university conceivably might design a particular instrument to measure parameters of interest, and then turn over all other aspects of the program to industrial subcontractors. For a small group concerned only with the basic space-science problem they are probing, such an approach could have merit. But for a large engineering school, potential beneficial interactions would be lost by this method.

We would propose instead that university people be concerned with every aspect of the project. We do not suggest that they actually build every part of the spacecraft (although they might do some prototype construction). But we believe that groups concerned with, say, structures, propulsion, electronics, communications, space physics, and orbits could well use the existence of the University Satellite Program as a focal area for broader, more meaningful involvements in the development of new concepts in their fields. For example, the communication engineers might be motivated to work with a graduate student on a new approach to spacecraft communications after exposure to a less-than-perfect system being prepared for a current university satellite. If they were at all successful, a new idea might be tested on a later satellite and incorporated as a part of the spacecraft system in a still later satellite. Similar stimulus and response might also occur in the other areas of spacecraft structures, systems, and science.

Because of the multiplicity of problem areas involved, it appears that the University Satellite Program can serve to focus inputs from virtually the whole spectrum of educational and research interests of a graduate engineering school.

E. ADVANTAGES OF "STEADY-STATE" PARTICIPATION IN SPACE-FLIGHT PROGRAMS

We discussed previously certain difficulties in having graduate students participate in space-flight projects. Of particular concern is the lead time, the total duration of the flight projects, and danger (to the student's program) of mission failure. In a few cases it has been possible for a single student to follow a satellite experiment from inception through analysis. There are other examples where use has been made of rocket and balloon flights. However, we believe that, particularly for satellites and deep space probes, a different approach offers greater opportunity for significant graduate student participation.

We suggest that more graduate engineering students could participate in, and contribute to, NASA space-science and technology projects at their school if at any one time a number of space projects were evolving through different stages of development. There could then be a sort of "steady-state" condition whereby a graduate student could become acquainted fairly quickly with a range of the many aspects and many stages of flight-project development so as to have the background of information needed to define and attack most efficiently a specific dissertation topic. The results of his study in depth of a relatively narrow subject might then feed back into later flight projects.

Under such a steady-state program, different students might be working simultaneously on dissertations that include, for example: theoretical characteristics of a planetary atmosphere; potential measurable parameters and measurement techniques for future studies of planetary atmospheres; communication theory aspects of a proposed measurement technique; new devices and instrumentation needed for future measurements of planetary atmosphere; detailed design and analysis of such instrumentation for a current flight; and data analysis and scientific deduction using results from previous space-flight measurements of a planetary atmosphere.

A steady-state program of this sort would involve students in activities ranging from the planning of new experiments to the analysis of old experiments, with emphasis on a specific problem (for example, the characteristics of planetary atmospheres). A steady-state program could also develop breadth in subject matter, including such topics as propulsion, trajectories, structures, space physics, communications, and thermal control as related to future, current, and past projects.

Opportunities for interactions in such a program would be very great indeed. In contrast, a single study, isolated from the others, would surely suffer from the lack of such close and continuous reference to related aspects of space-flight experimentation.

In order to reach a steady-state condition, it is obvious that the number of engineering school participants must be relatively large. Probably a critical size is needed before the group can "catch fire" and work under conditions that include significant interactions. However, not all professors and students could (or should) spend an appreciable part of their time in maintaining such interactions; a relatively few people could spark the interplay. The majority could continue essentially in the way that they would if they were more isolated but with the significant difference that they would on occasion be exposed to the broader program areas so as to experience the valuable influences that such exposure would bring.

For a small engineering school, it may not be possible to reach this critical size. In this case, special efforts should be made to combine forces with other universities, and/or with a NASA center. Also, participation in such activities as the ASEE-NASA Summer Faculty Fellowship Program, or the NASA Resident Research Associateship Program at the centers would be particularly important when it is not feasible to maintain a high level of participation in NASA flight projects at a particular university.

F. ADMINISTRATIVE MECHANISMS

If a coherent program of space-related research is to grow within a university, it is essential that attention be given to administrative mechanisms which will encourage faculty and student participation. A successful program requires popular acceptance; cooperation is based on shared enthusiasm for common goals. The importance of a focusing mechanism has been emphasized earlier. The form of administration of program funds is equally important. These administrative mechanisms must positively recognize that faculty participation in research at a university cannot be forced but will grow naturally in the proper environment. The faculty must be assured that in committing themselves to space-oriented research in a genuinely multidisciplinary association they will not risk loss of the security and continuity of support that they may have otherwise generated by their individual efforts.

There are a number of administrative patterns that might be followed. The optimum form in a given situation is certainly dependent on the general practice of the university; it is conditioned, too, by the nature of the research emphases. The format to be described in the following paragraphs is adapted to organizational situations such as found within the Stanford Engineering School, in which the ultimate authority for the research program rests not with the faculty but with the Dean of Engineering. The Dean continually makes decisions on budgets, promotions, housing, and new faculty additions which serve unobtrusively to guide the course of the engineering school. He is, however, assisted by an executive committee, representing the various departments of engineering. Thus, final administrative control of research rests at the school level (rather than with departments or divisions) with a general and equal access by all faculty to that administration.

With this background and experience, we suggest that administration of a multidisciplinary engineering program and its funds should also be the responsibility of a single Executive reporting directly to the Dean. To function well, this form of organization requires certain key attributes on the part of the Executive. Most important, the Executive must maintain wide-open channels of communication with the faculty. He cannot delegate this responsibility. He must, on his personal initiative, poke his nose into research laboratories, drink coffee with the faculty, attend seminars and bull sessions, and become not only personally knowledgeable with respect to the nature of faculty space research but also known to be so by the faculty. In short, only a knowledgeable and communicative Executive can marshal the enthusiasm on which a common program depends. In much of the present more individualistic project-directed research activities, such leadership is neither necessary nor apparent, and lack of communication is indeed sometimes looked at as the advantage of "being left alone." However, for a growing program or a cooperative venture, a more active form of leadership becomes desirable.

More formal channels of communication and advice are also essential for the Executive of a multidisciplinary engineering program. An Advisory Committee without executive powers should be at the Executive's disposal. It is important that this committee not become a buffer, taking the place of direct contact between the Executive and the faculty. However, the Executive does need assistance in formulating policies, and performance must be reviewed. The Advisory Committee can represent the proper spectrum of backgrounds if it consists of about eight members. In order to maintain a wide base of representation and a fullest sense of faculty participation, the membership should be rotated annually on the basis of staggered three-year terms. Five or six of the members should be selected from faculty active in space research. The remaining two or three should be faculty not presently so involved. These members would serve to make the Committee more representative of the Engineering School as a whole, and to discourage inbreeding in the program. They would also serve to improve communications and broaden the range of space interest throughout the school.

The Advisory Committee should not make decisions on financial support of faculty research. In addition to freeing closely involved faculty of the onus of judging their colleagues, the speed and flexibility of action that Executive decision makes possible are of great utility. The Advisory Committee should periodically review the scope of the program and examine the past actions of the Executive. In this way the group can help guide the overall direction of the program. It is important that the minutes of the Advisory Committee meetings be carefully and informatively written and distributed to the whole engineering faculty. Communications should also be maintained by the fullest possible written documentation and dissemination of other matters relating to the program.

It is suggested that both project and multidisciplinary funds are important to a complete space-research program. The retention of the opportunity to develop outside project support is vital for large specialized activities (even when associated closely with the space effort) and for providing a recourse for faculty whose interests do not coincide precisely with the main stream of the multidisciplinary program. But within the multidisciplinary program the base of support should be as broad as feasible and should not be confined to just a few major projects. In this way the program will receive the greatest popular support, while drawing on the largest reservoir of talent and ideas. It is important that a full spectrum of activity be supported from direct participation in space experiments to long-range studies. The basic mission of NASA is long range and continuing. The universities have a broad role to play in developing basic science, plans, and engineering for missions of the future.

If both multidisciplinary and project funding are to exist together at an engineering school, the relation between their amounts is significant. It is especially important in the long view that multidisciplinary and project funding not become unbalanced, because, perhaps, of a long-term growth in project activity. A continuing balance might be maintained by reviewing multidisciplinary funding in relation to a formula, such as keying increases of multidisciplinary funds to changes in project funds periodically averaged. No estimate will be attempted here of the exact portion of engineering space funds that might best be placed in block form, but the optimum range is probably somewhere between 25 and 35 percent. One of the advantages of university administration of such block funds, from the NASA viewpoint, is that it relieves the agency of the very large burden of administering a large number of separate grants. If say 25 percent of the funds are administered on this basis, the fraction of projects covered will be in excess of 25 percent, since individual project support will occur primarily with the larger projects.

A further consideration of factors affecting the administration of an engineering school program in space science and technology are given in Appendix E; this latter discussion is based on the viewpoints of the directors of the current broad programs in Engineering and Applied Physics at Stanford.

G. THE IMPORTANCE OF A CENTRAL FACILITY

In the organization of a cohesive and focused program in space engineering, factors of physical arrangement are quite significant. It has been well established in other connections that the number of contacts between individuals decreases as the square of their effective geographical separation. In relation to both student and faculty contact, the amount of communication is directly related to the ease with which informal contacts can take place. It is not possible that all areas of a large school, or even those parts of it which have space-related interests, can be grouped together. To do so would destroy other equally important groupings. However, just as a technical focus is needed to draw together the interests of the faculty, a geographical focus is needed to centralize communications relating to space problems. It is especially important that facilities for housing space research (as in any program-oriented research facility) not be looked upon solely as a source of research office and laboratory space. They should do more. An especially important function is to bring together students and faculty with a common interest. Classrooms, lounges, seminar rooms, libraries, and study areas provide the meeting ground which makes possible communications, cross-fertilization, and the enthusiasm associated with a joint endeavor.

APPENDIX A. STANFORD UNIVERSITY ENGINEERING SCHOOL STRUCTURE AND ACADEMIC RESEARCH

In this appendix we shall give a brief description of Stanford and of the Stanford University School of Engineering to provide background for the discussions in other sections of the report. The University began instruction on October 1, 1891. It is a coeducational, private school with a present enrollment of roughly 10,000 students, approximately 55 percent of whom are undergraduates.

At the top of the administrative structure is the Board of Trustees, having responsibility for all university properties and endowments, determination of salaries, appointment of the President and faculty, and the establishment and maintenance of the educational system. The President reports to the Board of Trustees, and has the power to prescribe the duties of professors and teachers, to prescribe and enforce the course of study and manner of teaching, to manage the business affairs of the University, and to otherwise control the educational aspects of the University. The Vice President and Provost is responsible to the President for administration of the whole of the academic program, including the various schools, unaffiliated units, and libraries (except the Hoover Institution). The Provost has as his principal officers a Vice Provost and Dean of Undergraduate Education, an Associate Provost and Dean of the Graduate Division, an Associate Provost for Research, the Deans of the Schools, the Director of the University Libraries, the Director of the Food Research Institute, and an Executive Assistant.

The academic activities of the University are administered through seven schools, with their deans reporting to the Provost. They are as follows: Graduate School of Business, School of Earth Sciences, School of Education, School of Engineering, School of Humanities and Sciences, School of Law, and School of Medicine. In addition, a number of activities which do not fall within the purview of the Schools are administered by the Associate Provost for Research. Included in this category are the Center for Materials Research, the Computation Center, the Hansen Laboratories (microwave research), the Institute for Mathematical Studies in the Social Sciences, the Institute for the Study of Human Problems, the Program in Operations Research, and the Biophysics Laboratory. Within the School of Humanities and Sciences are the Departments of Applied Physics, Biological Sciences, Chemistry, Computer Science, Mathematics, Physics, and Psychology, to name those most intimately related to activities of the space program. The School of Engineering has seven Departments: Aeronautics and Astronautics, Chemical Engineering, Civil Engineering, Electrical Engineering, Industrial Engineering, Materials Science, and Mechanical Engineering. In addition instruction is offered in the Division of Engineering Mechanics, the Institute of Engineering-Economic Systems, and the three divisions of mechanical engineering (Engineering Design, Nuclear Engineering, Thermosciences). Degrees are awarded in General Engineering and in Engineering Science as well. The faculty of the divisions and institutes are members of a department, but they have their own programs of instruction and research. The Department of Petroleum Engineering exists with the School of Earth Sciences rather than within the School of Engineering.

In addition to these major administrative departments and divisions, there are a number of other organizational entities established for the purpose of increasing the flexibility of the educational and research programs. There is, for example, the Committee on Hydrology, which administers Masters and Doctoral programs with participation from Civil Engineering and Geology. The Center for Radar Astronomy coordinates programs in that field carried out cooperatively between the University and the Stanford Research Institute. Again, the Institute for Plasma Research coordinates plasma studies within the departments of Applied Physics, Electrical Engineering, Mechanical Engineering, and Aeronautics and Astronautics.

In summary, the organization of the formal research programs (all of which are carried out in close association with the academic pursuits of the University) is in substantial contrast to that of the traditional departmental structure in Engineering; the research activities are directly responsible to the Dean, rather than the department heads. Flexibility is the keynote in this organization. The aim is to bring about the optimum associations of individuals--regardless of departmental affiliations--in order to guarantee the most productive research, and there are many examples of multidiscipline research efforts that cross both department and school boundaries.

As an example, electronics research is organized with the Stanford Electronics Laboratories (SEL), whose Director is also Associate Dean for Research. The SEL is divided into five sections: the Plasma Laboratory, the Solid-State Electronics Laboratory, the Systems Techniques Laboratory, the Systems Theory Laboratory, and the Radioscience Laboratory. The programs of these laboratories are carried out in a number of facilities, including the Electronics Research Laboratory and Applied Electronics Laboratory buildings, the new McCullough Building, the Hansen Microwave Research Laboratory, and numerous on- and off-campus field sites. Off-campus research is conducted at stations from Alaska to Antarctica, from Okinawa to Greece. The SEL engineering support staff supplements the University administrative services with the following services: internal accounting, drafting, film production, instrumentation, shop, patent, personnel, property control, publications, purchasing, stores, maintenance, travel, and document control.

From Fig. A-1 it will be noted that the bulk of sponsored research in engineering at Stanford is in electronics (through the medium of almost 90 grants and contracts). It may be noted also that the fraction of research supported at Stanford by NASA has risen sharply in the past few years; from 1963 to 1964 NASA support in Electrical Engineering doubled (not counting the Hansen microwave laboratories), and the total Engineering School support from NASA went up by about 65 percent, all attributable to the increase in electrical engineering. No NASA research support exists at Stanford in industrial, chemical, or civil engineering, or in engineering mechanics.

The growth of the sponsored research in engineering at Stanford over the past 10-year period is shown in Fig. A-2. Also shown is the research in the Hansen Laboratories and the Center for Materials Research. It will be seen that over this time span there has been an approximately four-to-one increase, though there is little current growth in evidence.

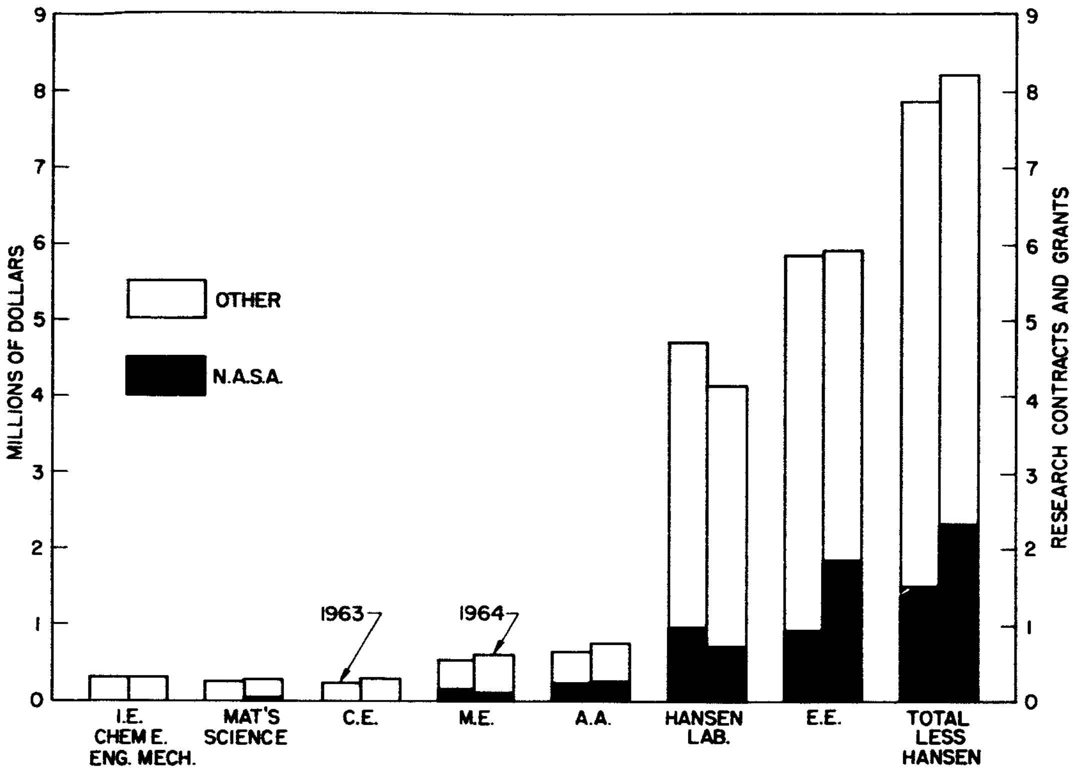

FIG. A-1. DISTRIBUTION OF RESEARCH.

The growth in support by NASA has largely resulted from a diversion of associations with the Defense Department.

The picture of research support, with its heavy emphasis on electrical engineering, is not in conformity with the overall structure and activity of the Engineering School as a whole. Figure A-3 shows by department the number of engineering faculty members whose rank ranges from Assistant to Full Professor. Although the Electrical Engineering faculty is the largest, the figures on dollars of research support per professor by department are illuminating. The average support per professor in Electrical Engineering is $120,000. In Aeronautics and Astronautics it is $41,000; in Mechanical Engineering, $34,000; in Materials Science (excluding the Center for Materials Research which is not within the Engineering School), $23,000; in Civil Engineering, $12,500; Chemical and Industrial Engineering support per faculty man from grants and contracts is similar to that in Civil Engineering.

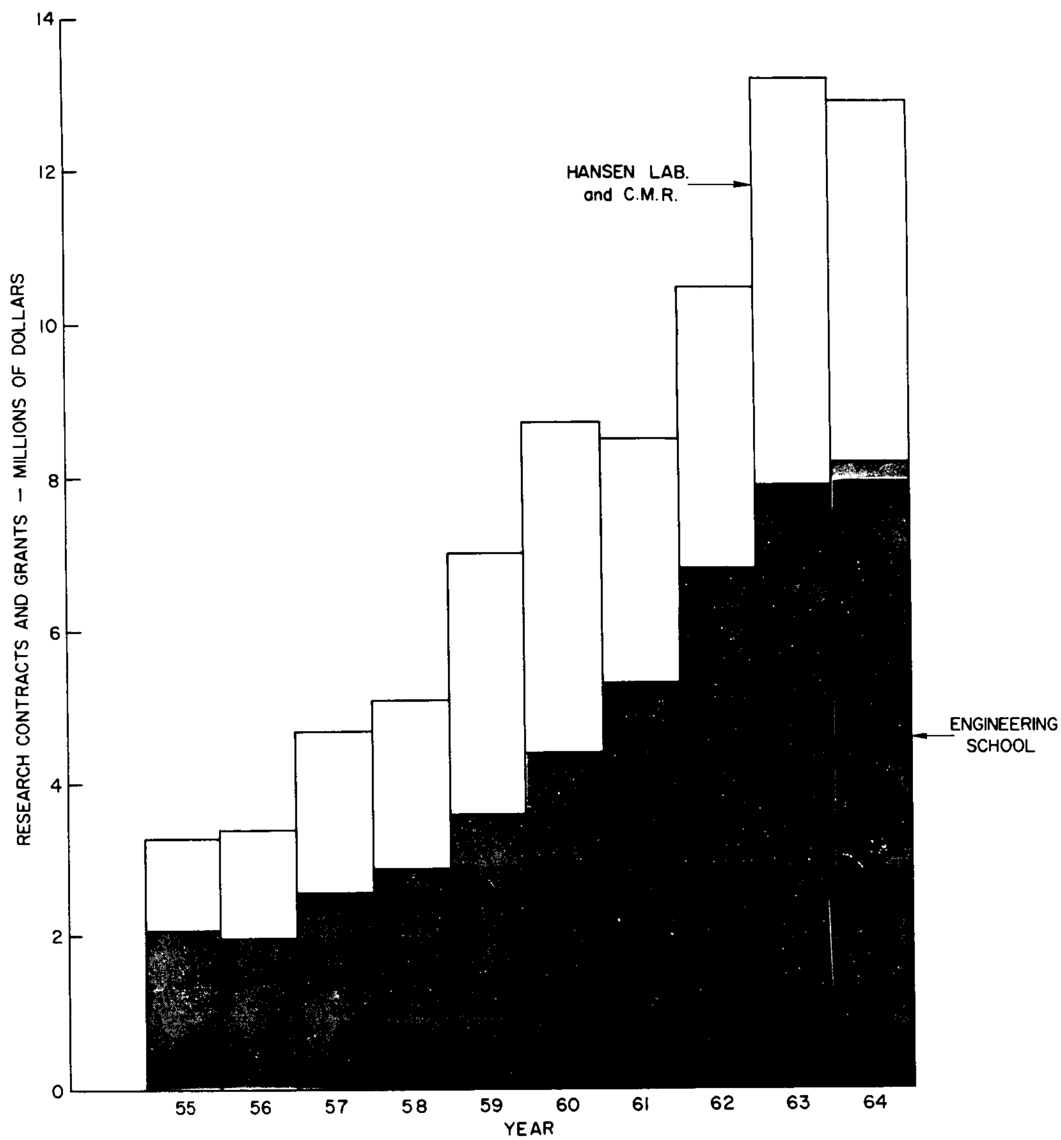

FIG. A-2. GROWTH OF RESEARCH.

As can be seen from Fig. A-4, the number of course offerings is divided relatively evenly among departments, with Civil Engineering offering the most varied program of instruction (in contrast with its low ranking in sponsored research).

Graduate enrollment by department is depicted in Fig. A-5. Electrical Engineering is by far the largest department in this category, with the traditional disciplines of Mechanical and Civil Engineering in third and fourth place. Second place has been taken by the newer Department of

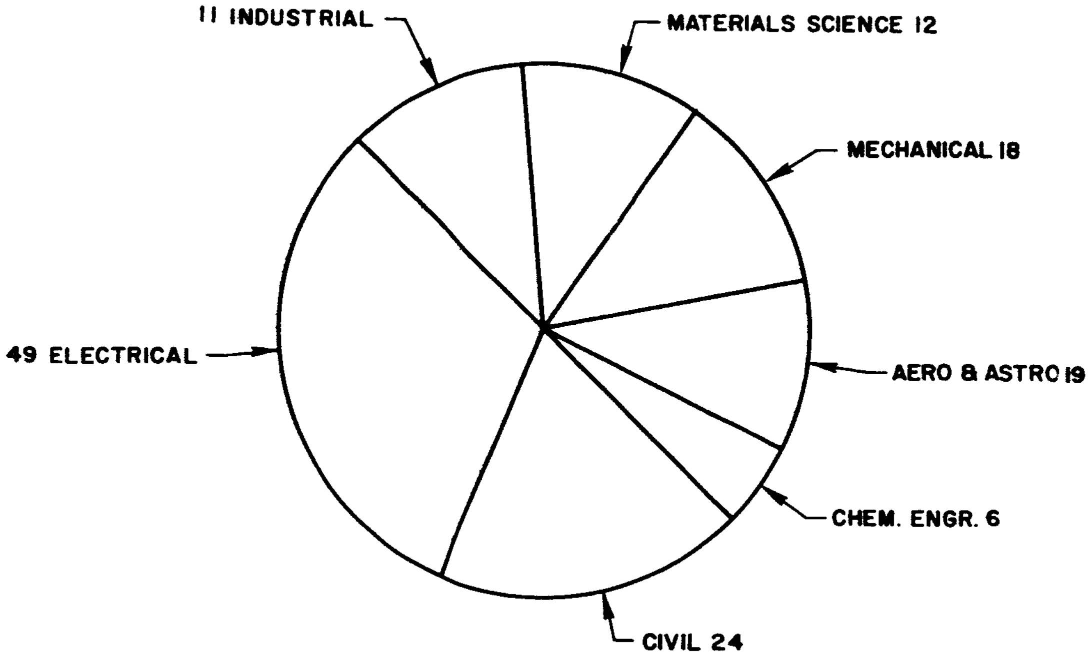

FIG. A-3. FACULTY BY DEPARTMENT.

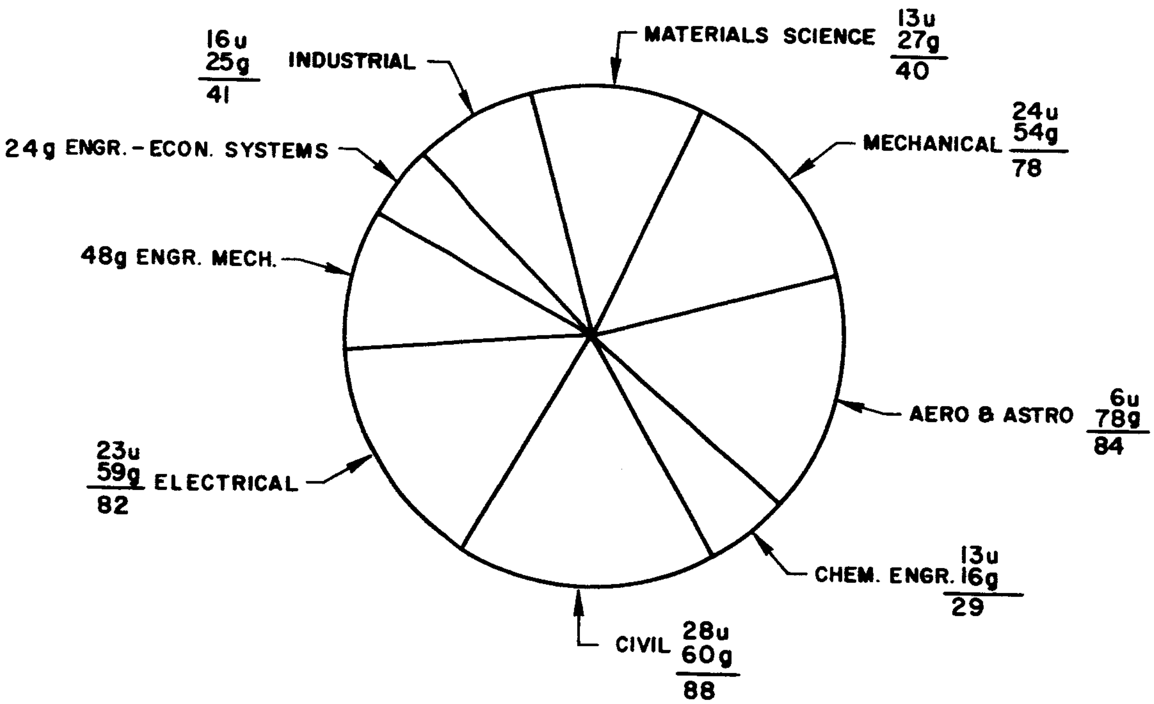

FIG. A-4. COURSES BY DEPARTMENT.

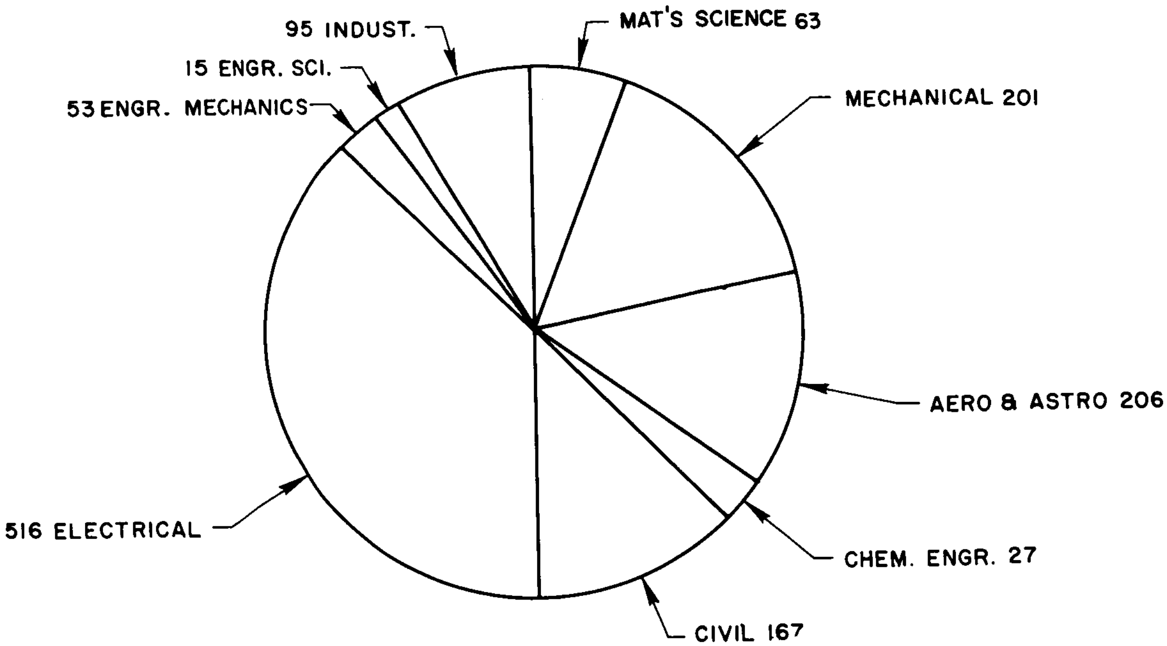

FIG. A-5. GRADUATE ENROLLMENT.

Aeronautics and Astronautics. The average number of graduate students per faculty member in Engineering is 8.6; the departments compare as follows: Electrical Engineering, 10.5; Materials Science, 5.2; Mechanical Engineering, 11; Aeronautics and Astronautics, 10.8; Chemical Engineering, 4.5; Civil Engineering, 7.0; and Industrial Engineering, 8.7. The average number of dollars of sponsored research per graduate student in Engineering is $7200. By department, the figures show Electrical Engineering (55), $11,400; Materials Science (13), $4,500; Mechanical Engineering (13), $3,000; Aeronautics and Astronautics (20), $3,800; Civil Engineering (11), $1,800; and Chemical Engineering (12) and Industrial Engineering (5), $2,500 per graduate student. (The figures in parentheses give the number of Ph.D. degrees awarded last year by the department.)

As is shown in Fig. A-6, within the last three years there has been little overall change in the total numbers of engineering degrees awarded at Stanford. However, the mix has changed, and a strong trend is evident in the direction of increased numbers of advanced degrees and a decreased number of undergraduate degrees. Especially notable is the decline in

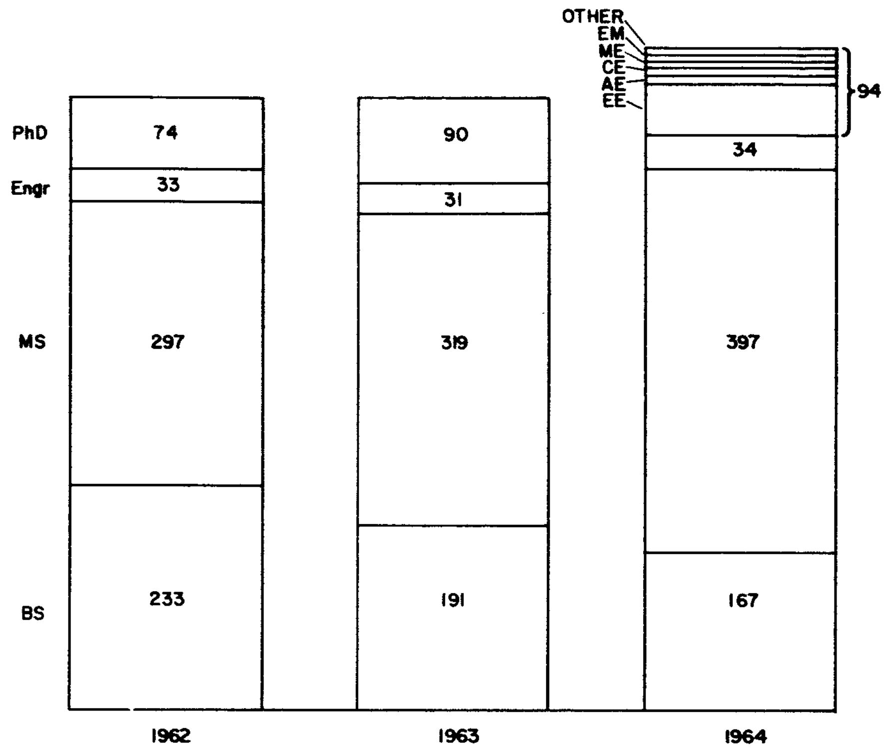

FIG. A-6. GRADUATE DEGREES.

B.S. degrees and the compensating increase in M.S. degrees. Some increase is also evident in the number of Ph.D. degrees. The decrease in B.S. degrees is a reflection of the interests of incoming freshmen of a number of years ago. The decline in the number of freshmen electing engineering majors has only been arrested in the last year.

APPENDIX B. DESCRIPTION OF THE SPACE SYSTEMS ENGINEERING COURSE

1. Introduction

In the winter and spring quarters of 1965 a course on "Space Systems Engineering" was given at Stanford for the second successive year. Although an engineering school course, participation included students from outside departments. The brief description of the origin and nature of the course which follows formed the Preface of a summary report of 39 pages to the 1965 SAMPLER (Stanford Advanced Mars Project for Life Detection, Exploration and Research) project, as the student study was named. The table of contents of the summary report is then given to show the general scope of the study. There follows next the description of the course which was distributed to students prior to registration in the winter of 1965. A full report on the earlier SWAMI study of 1964, of about 400 pages, has been published, as will be a corresponding final report on SAMPLER.

2. Background of the Course (by Professor William Bollay)

During the summer of 1961, I participated in a meeting of engineering educators in Boulder, Colorado, under the sponsorship of the NSF to review various possible methods of strengthening engineering education. One of the major recommendations of that meeting was that engineering design should be taught whenever possible by giving the students an opportunity to participate in real design situations.

During the following summer I was managing an exploratory study on new applications of astronautics. This study concluded that satellite technology made feasible vastly improved methods of weather forecasting on a global scale. Specifically, it recommended for engineering analysis the following systems:

1. An equatorial satellite system for the direct readout of cloud systems in the equatorial belt of the earth--for ships at sea and for the underdeveloped countries.
2. A satellite system for collection of numerical weather data to provide the inputs to a digital computer for automatic weather prediction.

While these studies were going on, I received an invitation from Dr. Stark Draper to spend a year at MIT as a Visiting Professor. He expressed a particular interest in having me introduce some exciting realistic design projects into the curriculum. This invitation, therefore, presented a double opportunity as far as I was concerned--to experiment with a group of advanced students in tackling a real preliminary design problem and to extend the analysis of some of the weather satellite systems. I accepted this offer from MIT and proposed the organization of an interdisciplinary course in systems engineering. This program was started during the spring semester, 1963. We studied the equatorial weather satellite system by organizing a class of over 60 students as a preliminary design team. This experiment was a tremendous success both from the standpoint of motivating the students and of giving them an opportunity to participate in a creative engineering design. They made a number of significant technical contributions, and their report was welcomed by both industrial and government leaders. This course was entirely university-supported with no government funding. However, many visiting lecturers from industry and government made a significant technical contribution by presenting the state of the art in their technologies.

During the academic year 1963-64, I was invited to repeat this experiment at Stanford University. We selected the global weather data collection system as a project and the class of 30 graduate students again performed an excellent study with similar results as at MIT.

3. The 1965 Study (by Professor Bruce Lusignan)

A Mars exploration system is the subject of this year's Stanford study. This is one of the most complex problems facing the space industries and was a great challenge to the students. While challenging them, the course also sought to train the students for the very complex and important field of systems engineering. They were given an opportunity to use knowledge in their own specialty, to gain understanding in other fields, and to see their interaction in an integrated systems design. The students were acquainted with the space industry through guest speakers and visits to various facilities. Finally, they learned how to approach systems design problems where it is often harder to ask the proper questions than to acquire the technical answers.

That this study has accomplished its educational aims is quite clear. It produced aeronautical and astronautical engineers who understand communications parameters and TV requirements, mechanical engineers acquainted with electronic power requirements and interplanetary solar wind experiments, electrical engineers who understand orbit calculations and biological laboratories, industrial engineers and business majors who understand the dynamics of systems design decisions, biologists who appreciate the engineering constraints and possibilities of Mars missions, and probably the only philosopher who knows how and why to go to Mars. The student design teams that have developed are as efficient as any I have observed in industry.

I feel that the students have benefited from the course, and NASA and the space industries will also benefit from the SAMPLER report. The study, which is briefly summarized here, contains original designs and innovations which should make significant contributions to the actual Voyager project.

4. Class Organization

The group of 50 students was broken into four study groups. These four groups were chosen to break the overall systems design into three basic subsystems and a design coordination and planning group. Group A was responsible for the definition of the various scientific experiments to be performed and the design of the required instruments. Group B specified launch vehicle requirements and analyzed possible trajectories and modes of vehicle stabilization. Group C designed the orbiter and landing packages including the electronics, power supplies, temperature controls, and communications for these vehicles. Group D did the scheduling and cost analysis for SAMPLER and analyzed the economic and political factors inherent in such a program as well as serving as an overall project coordination group.

Each group had a faculty adviser and twice each quarter elected a group leader. The four group leaders then chose from among themselves a project manager. The project manager and the group leaders were then responsible for one of the four phases of study. The first phase studied long-range plans for the United States in space, and studied the capabilities of various booster systems and space probe technology. The second phase defined the major engineering approaches and chose the mission to be defined and evaluated. In the third phase, the many previous decisions were confirmed or changed and the detailed design work was completed. Final calculations were done and the final report organized and edited during the fourth phase.

5. <u>Partial Table of Contents for the SAMPLER Summary Report</u>

CHAPTER IV - THE LANDERS

A. Entry and Impact Attenuation Systems

B. Lander Design

C. Electronic Systems

D. Sterilizations

E. Breakdown of Entry Vehicle Weight

CHAPTER V - TRAJECTORIES

A. Introduction

B. Earth-Mars Trajectory

C. Martian Orbit

D. The Lander Trajectories

E. Landing Site Selection

6. Announcement of the 1965 Space Engineering Course

a. Introduction

In 1964, a satellite-system engineering course was started at Stanford. The purpose of this course was to give graduate engineering students in different fields experience in working together on a realistic engineering system design. The 31 students in the course completed a preliminary design study of a global weather satellite system. The study included choice of the number of satellites required and their orbits, design of remote weather-sensing buoys and balloons, analysis of position determination from satellites, design of the communication links between satellite and the 5000 remote stations, design of the satellite (including stabilization, power supply, heat balance, and electronics), and design of the launching rockets. The course proved successful both in providing a valuable experience for the students and in producing for government and industry a final report that contains both new approaches to satellite weather systems and realistic analyses of existing approaches.

In view of this success, the course will be offered again in winter and spring quarters 1965. The object of this year's study is an unmanned space vehicle for early investigation of the planet Mars. An instrument package is to be landed on the Martian surface and information from it transmitted back to earth. The mission may involve landing a package on Mars with transmitters powerful enough to reach earth, or placing the main spacecraft in orbit about Mars to relay signals from a less powerful surface package. This decision and many other similar ones would be made by the class during the study.

The Mars exploration mission was chosen for several reasons. It is a topic which will be of great interest to the students. It presents a well-defined problem with many clear alternative approaches to be evaluated. Since this topic is of great interest to NASA and the space industries, many highly qualified guest speakers will be easily available for the class. And, finally, several research groups at Stanford are directly involved in Martian exploration: a group in the Radioscience Laboratory which is studying planetary atmospheres and groups in the Medical School and in Mechanical Engineering which are designing biological instrumentation to detect life on Mars. These groups will contribute students for the class and guest speakers, and, in turn, will obtain valuable knowledge of the engineering difficulties and possibilities in such a mission.

b. Invited Speakers

About twenty representatives from universities, government, and industry will be invited to talk to the class during the first quarter. Representatives from Goddard Space Flight Center, the Jet Propulsion Laboratory, and NASA-Ames will describe their studies of present and future Mars probes. Various experimenters will describe the experiments they wish to include on such a mission. Manufacturers' representatives will be invited to describe airborne computer systems, rocket booster and launch vehicles, stabilization systems, power sources, etc. During the second quarter, speakers will be invited mainly when the class requires more information on specific topics.

c. Student Enrollment

The class will be composed of graduate students, primarily from the School of Engineering, but also including a few from the Biology

Department or the Medical School. As many as 50 students can be handled effectively although the class will function properly with half that number. An appropriate distribution between the departments is shown below:

EE: Communications (4), Radar Astronomy (4), Control Systems (4), Computers and Circuitry (4), Data Processing (3), Power Sources (3).

ME and AE: Orbit Mechanics (4), Structures (4), Rocket Boosters (4), Temperature Control (3), Aerodynamics (3), Platform Stabilization (3).

IE: Cost Analysis (3), Industrial Management (2).

Biology: Exobiology (Planetary Life) (2).

d. Course Outline

At the start, the class will be divided into several groups: Scientific Experiments, Trajectories and Control, Spacecraft and Communications, and Design Coordination and Support. Each group will elect a Group Leader and Assistant Group Leader, and these in turn will select a Project Manager. These Group Leaders will meet weekly to decide what problems should be covered by each group and to make major decisions on the project. Each month, the Assistant Group Leaders will become the new Group Leaders, and a new Project Manager and new assistants will be selected.

During the first two-thirds of the first quarter, the characteristics of the mission are to be obtained and the major alternative approaches are to be clearly defined. By the end of this quarter, these approaches are to be evaluated and the best approaches chosen. Detailed design of mission components will occur in the first two-thirds of the last quarter. In the final third, the design is to be frozen, and final reports and the class presentation are to be prepared.

e. Presentation and Final Report

At the end of the second quarter the class will make a two-hour presentation of their results to industry and government. In the remaining three weeks, some of the students will edit the individual final reports to form a comprehensive report of the total system.

f. Faculty

The course will be organized and directed by Dr. Bruce Lusignan with the assistance of Dr. William Bollay, who conducted the course last year. Faculty advisors to the design groups will be Daniel DeBra (AE), Bruce Lusignan (EE), William Lapson (ME), and Robert Hemmes (IE).

The following faculty members are conducting research connected with the Mars project and have accepted invitations to give individual talks to the class:

Dr. Levinthal (Med. School), Dr. Eshleman (EE),
Dr. Garriott (EE), Dr. Cannon (AE), Dr. Bulkeley (ME),
Dr. Breakwell (AE), Dr. Lederberg (Med. School),
Dr. Seifert (AE), Dr. Siegman (EE).

APPENDIX C. THE INSTITUTE IN ENGINEERING-ECONOMIC SYSTEMS

1. Introduction

The Institute in Engineering-Economic Systems (IEES) at Stanford University is an interdisciplinary, interdepartmental organization developing a broad graduate research and coursework program in the area of engineering-economic systems. The three specific objectives are (1) to develop interdisciplinary research activity in systems, (2) to establish industrial and governmental internships in the field to couple theory and practice, and (3) to present in courses system concepts derived from foundation courses in mathematics and physical and behavioral sciences on the one hand and practical casework on the other.

The Institute provides a center for research and project work on problems that require integrated contributions from several disciplines, especially from engineering, economics, and management. Attention is focused on areas in which planning and system considerations dominate. Particular stress is placed on study of physical or operational systems with complicated interaction between parts; on those situations in which decision-making must take place under uncertainty; and on those situations in which characteristics or states evolve with time and in which control is a significant factor. In general, model making and computer simulation are emphasized; the various optimization procedures receive strong attention.

Since system problems are problems of the real world, an environment for interaction with the real world for both training and research purposes is provided in two complementary ways. The first way is to immerse the student and the professor in difficult casework problems by taking them to the scene of the problem-solver in the field. To this end internship programs have been established with industry, research organizations, and governmental agencies at home and abroad. The second way is to bring problem-solvers from the field to the university, to free them from daily administrative chores, and allow them to regenerate their approaches through study and interaction with students and faculty, thus contributing to the mutual growth of all three parties. This is done at

Stanford through the institution of Industrial and Government Fellows in Engineering-Economic Systems.

Professional work in the systems field requires a broad background in the foundation disciplines of mathematics and physical and behavioral science, obtainable from any strong graduate university program. Upon this foundation, professional competence must be built. Present professional courses in engineering and management, however, usually tend to be too specialized for systems training. New professional courses are being developed by the Institute which stress connections to both the foundation disciplines and to field work. Where appropriate, these courses are offered in existing departments in engineering or management. Several new interdepartmental courses are offered directly by the Institute.

As examples of the types of problems which fall within the range of interest of the Institute are the following:

1. Urban transport
2. Satellite weather observation
3. Control of industrial inventories
4. Regulation of air traffic
5. Establishment of new businesses in underdeveloped areas
6. Development of automated instruction
7. Efficient use of water resources
8. Marketing of new products
9. Scheduling and control of production
10. Long range corporate and government planning.

Although the activities of the Institute have not been related to NASA in the past, it is clear that NASA has many problems of the nature that the Institute in Engineering-Economic Systems is designed to explore. It appears that internship program arrangements between NASA and suitably inclined universities would be of mutual value.

Two discussions relating to (1) systems training and (2) the internship program constitute the remainder of this appendix. These discussions will serve to explain in greater detail the nature of the program which is developing. Although originally prepared for other purposes in mid-1964 by William K. Linvill, the director of the Institute, they are still pertinent.

2. System Training through Internships in the Field

a. Introduction

Rapid technological advances have expanded the role of the university in our society and have imposed changes in its function. In this paper we will examine the function of the university in some detail, and attempt to describe it in general terms. In particular, the role of the university in developing the professional field of System Engineering will be considered. The area of system design requires new theoretical breadth and poses new problems for the engineering school. Breadth in mathematics and in physical and behavioral science is essential. Interaction with real-world problems to tie down the theory can be provided by industrial internship. The complementarity between university and industry needs make such internships mutually advantageous. A specific internship program in System Engineering between Stanford and Westinghouse will be described and its possible extensions and generalization will be explored.

b. University Function in Times of Rapid Technological Change

Rapidly changing technology has made drastic changes in patterns of life during the past twenty-five years, and promises even more extensive changes in the future. The function of the university in this environment needs to be examined carefully. Traditionally, and for enduring reasons, the function of the university is to collect, restructure, and transmit knowledge. The radical changes in our physical environment have made this function, if anything, more important now than it was in the past.

The school of arts and sciences in the university is particularly dedicated to the traditional long-range function described above. Planning academic work involves tension between the extremes of isolation from the world and close interaction with it. Close connection with the past and isolation from the immediate present prevents corruption of the academic processes by events which are important primarily because of their immediacy. Thus isolated, the structuring process can stay fairly close to traditional philosophical principles. Isolation from the world is hazardous when the world is in a state of fast change because important real-world data may be delayed or even lost to the academic community because of the impedance of the isolation barrier.

The function of the professional schools in the university is markedly different from that of the schools of arts and sciences. The aim of the professional schools is the technical training of students to be <u>useful</u> in the solving of problems in the real world. It is obviously essential to have a much greater degree of coupling with the real world for professional schools than for schools of arts and sciences. In a period of fast change in the real world, the impact of the world on professional schools is obviously much greater than its impact on schools of arts and sciences. One key point of this paper is that in periods of quick world change, the coupling between professional schools and schools of arts and sciences must be made tighter. Similarly, the coupling between the professional school and the real world must be made tighter.

Let us consider the relationship among the various groups in our society who are concerned with academic or technical matters. One interesting model of the academic community is provided by visualizing the various kinds of activity as layers around a core. The classics provide the core of the intellectual activity. They are sheltered from the outside world and are characterized by extremely long term activities. In engineering terms we would say their time constants may be in the order of a hundred years or so. They make changes to adapt to the world on a very deliberate basis. Another layer of intellectual activity is provided by the schools of arts and sciences in which the time constants are substantially shorter than those of the classics. Areas such as mathematics, physics, economics, and political science are examples of such areas. Perhaps time constants in the order of 50 years are appropriate to characterize this area. Still another layer is represented by the professional schools. They are devoted to professional training of students for the real world in ways which will be useful during their professional lifetime. Time constants in the order of twenty years are appropriate to this sort of activity. Still another outer layer of the intellectual activity is represented by work in research institutes and the research laboratories of industry. They usually have time constants in the order of five years. The companies having commercial interest and the government entities making significant direct action must see responses from their efforts within two years.

The forces of the outside world are often sharp and uncertain and are usually felt at the outer layers directly. These forces or stimuli are usually fed inward from outer layers to those next toward the inside. The philosophical structure developed in inner layers provide a monitoring function to activities in the outer layers. They also provide a good means for extrapolation in time to those working in outer layers.

Fairly close interaction between neighboring layers is essential. One stimulates the others. In situations of sharp change in the outside world there are strong forces to pull the layers apart and the ties between them must be adequately strengthened to survive.

c. Professional Activity in System Engineering

In the Institute in Engineering-Economic Systems at Stanford University we are devoted to building a professional activity in System Engineering which is meaningful for the real world and is consistent with the principles developed in a mature and well-stabilized academic structure. We are attempting to build a pattern of interaction between the professional school and the adjoining layers, both academic and practical, which is consistent with our image of them. Our particular emphasis is on engineering and planning, and our particular coupling to the foundation disciplines is in science and mathematics. Accordingly, our concerns will be particularized to these areas, but hopefully the principles are of broader applicability.

Engineering training in the past has been typical of many professional training programs. The strongest coupling to arts and sciences was the requirement for engineers to have a good background in mathematics and physics. Once the students obtained this initial start there was often little further interaction between engineering schools and mathematics and physics departments. Largely, the students were prepared for their real-world encounters, on the campus by laboratory work and practical engineering problems tailored for the classroom, and, once they got into industry, a modest amount of on-the-job training. With the traditional specialization, this procedure worked well and was adequate except for a few individuals who would want training for engineering research or for others who would want to attain some management skills along with technical skills. The first group would take graduate work in science or a mixture of science and engineering, while the second would take training in business. So long as the field was fairly static, the procedure was adequate.

At the outset of World War II when new technology was being created to meet the needs of the war, the engineers who were being called on to help in the new developments often found themselves badly outclassed by mathematicians and physicists whose broader academic approach gave them much greater flexibility to move from field to field. As a result, the physicists and mathematicians did much of the engineering research and development during the war, and after the war there was a swing toward "Engineering Science" in the engineering schools and a swing away from connection with real world problems.

As the technological advances made for military goals were applied commercially, two effects became outstandingly important: (1) economic and management factors now needed to be included for consideration along with the broad range of technical factors, and (2) it became much more difficult for individual engineers to relate their academic training to an adequate range of real-world problems. The breadth of practical experience needed to provide an engineer with the practical concepts might take him 10 or 12 years after graduation. The present group of successful system engineers and operations researchers often are men in their late 30's or early 40's who started with science or mathematics training and who spent their years since college in a variety of different jobs.

Our premise is that good system engineers must have both broad theoretical competence grounded on foundation disciplines from the academic inner layer, and broad practical competence gained from carefully controlled experience in the field (the outer layer). Only by close coupling among the three adjacent layers can a really strong engineering discipline be achieved. Table 1 below shows a fairly detailed pattern of our program with its interconnections.

TABLE 1. A SCHEME TO TIE SYSTEM ENGINEERING BOTH TO ACADEMIC CORE AND TO THE REAL WORLD

Mathematics	Modeling of Dynamic, Multi-variable Systems	Computer-Coordinated Systems
Physics	Probability, Decision-making Under Uncertainty	Industrial Development Planning
Economics	Optimization	
Political Science		Engineering-Economic Planning in Public Sector
Foundation Disciplines	System Engineering Core	Casework in the Field

Generally, the stronger background a System Engineer has in the foundation disciplines, the more easily he can shift from field to field in the real world. Experience in the academic world in which the disciplines are devoted primarily to being philosophically consistent and complete provides a man with a life-long set of concepts and values to live by. Fairly radical changes among casework areas in the real world are possible if one is adequately grounded in the foundation disciplines.

Effective working in the real world comes only from experience in structuring the real-world problems according to a set of basic principles derived from the academic core. Yet the principles in the academic core do not fit the real world situation well. The problem of approximating to the real world from the principles found in the academic is very interesting indeed. The example provided by computer or data-processing systems in the real world is noteworthy at this point. Computers provide such a convenient and simple means of mechanizing simple repetitive operations that their effect on the real world is to make the coordination of large systems now feasible. For example, it is possible to tie together the operation of a whole steel-making plant by means of a central data-processing system. Whereas in the past, the procedure was to operate the plant so that the separate parts did not interfere with each other, now the procedure is to coordinate the separate parts so that they operate more effectively as a unit. Dynamics problems arise in connection with this interaction which do not fit very well into the traditional patterns of physical dynamics, and yet which have important similarities to these patterns. Allocation problems are similar to maximization or minimization problems of the past, but the number of variables and the facility that computers provide for evaluating them lead to a problem of a different scale than was encountered before. Facilities for data gathering make market projections and production scheduling problems now workable where before they could only be conjectured. The engineer who has a broad familiarity with fundamental principles will obviously have a place in the new field of computer systems.

Since the fit of classical models to the new situations is only very approximate, experience in the foundation disciplines is, while necessary, clearly insufficient. The place of the professional school as a bridge between the real world and the academic core is manifest.

Given that the professional school must form a bridge between the arts and sciences and the real world, our next question is one of method. In the past, the engineering schools set up laboratories of their own on the campuses in which they did work which quite closely simulated problems of the real world. In the new day of larger, more complex, and more expensive systems, the problems of the real world simply are not portable. The world must be our laboratory! Whereas the older problems in engineering could be worked on the campus, the newer ones can be encountered only in the field. The problems that are brought to the administration of engineering school affairs are new to engineering schools but are very similar to those having been encountered by medical schools for many years. Both for teaching and research in medicine, connection of university medical schools with practicing hospitals is well established. This pattern of cooperation is a relevant one for engineering schools to consider.

d. Compatible Objectives and Complementary Needs of University and Industry

Since coupling between the real world and the university involves independent entities, cooperation must be based on mutual advantage. Mutual advantage will be shown to exist and a procedure will be suggested to exploit it.

The primary function of the university is to gather, to restructure, and to transmit knowledge. The professional schools have the somewhat specialized function of doing research to develop philosophical aspects of practical fields and of training future practitioners of the new disciplines. In their development of the new field, there is the inevitable necessity to relate this new field to the established philosophical framework of the arts and sciences. Thus, professional schools couple the arts and sciences to the real world at the same time that they avoid the corruption of the arts and sciences which would occur if these components dealt with the real world directly in enough breadth to do their data collecting alone. A primary theme of this paper has been the need of the university for coupling with the real world. Let us now turn to the interests and needs of industry.

Fast-changing technology imposes new demands and provides new opportunities for industry. Much as in the case of the university, industry has problems of adapting the old patterns of operation to the new situations. For example, automation provides remarkable advantages for industry, but it also brings substantial financial risks as well as problems of fast obsolescence of both human and physical resources of industry.

Because of the high risks involved in getting into new areas, careful preliminary exploration is vital. The philosophical breadth furnished by the university is extremely valuable in such exploration. Technical capability of its engineering staff is a capital resource of a company. This resource is depreciated by obsolescence. Such obsolescence can be prevented only by a continual process of training and research to keep the engineering staffs up-to-date. Thus, the industry needs the university for both exploration and training.

Having established the mutual need for university-industry cooperation, we now look at the pattern for it.

e. A Pattern for University-Industry Cooperation

Extensive interaction is valuable across the university-industry interface provided by professional schools of the university, and research and development laboratories of industry.

Commonly accepted consulting activities of engineering professors can be extended so as to provide for as much as 20 to 40 percent of the professor's time to be applied to industrial problems. If the professor's industrial activity is related to the work of his graduate students, his industrial consulting can provide a continuing vital input to the development of his professional field. While the professor assumes responsibility for <u>projects</u> in industry, he does not assume responsibility for industrial <u>programs</u>, and, thus, is free to devote his main energies as architect of the discipline. Graduate students, as well, spend on the order of two full years of a five-year doctoral program in the industry where they accept and discharge project responsibility. Their project-directed casework in industry is followed by concept-directed casework at the university which translates real-world practice into engineering principles through thesis research.

From the standpoint of industry, the exploratory work done at the research laboratory in collaboration between industrial and academic personnel can be carefully evaluated by industry from the extensive analytical data provided. Those promising projects can be further developed, and follow-through in industry for profit is the natural outcome.

f. The Westinghouse-Stanford Internship Program in System Engineering

For the past three years Stanford has had a pilot program of Industrial Internships in System Engineering with Westinghouse Electric Corporation. Projects at the company include:

1. Automation of electric power plants for generator control, plant operation, and load dispatching
2. Simulation and design of dynamic scheduling processes for steel mill operation
3. Modeling and control of basic oxygen furnaces for steel refining
4. Scheduling and control of public transportation systems
5. Computer analysis and design of magnetic structures
6. Exploration of computer usage for automated instruction.

Graduate students involved in the program spend periods of from 6 to 15 months on projects, at the company, doing technical work for which they are primarily responsible. These project-directed casework assignments are alternated with periods spent at the university taking graduate courses and doing concept-directed casework to follow up and generalize work done at the company. After about 4 to 5 years involving a total of from 18 to 24 months at the company, the student completes his thesis at the university, meets the regular academic requirements fully, and is granted his doctorate. The students in this program generally have as much or more coursework in mathematics and physics than the usual doctoral students in engineering. They will have had more practical experience at the company than most students and immediately upon graduation they can take responsible positions either in industry or academic life.

A professor from the university generally spends his summers at the company, and several weeks during the academic year there. His position at the company is one of a staff consultant. He does not supervise the students there, but does behave as a consultant to the projects with which they are associated.

Engineers from the company staff spend several extended periods at the university in pursuing new areas in which the company will become engaged. Usually the engineers have had from 5 to 10 years experience with the company when they come to the university.

Students are paid the usual industrial rates for their work at the company and are supported on subsistence fellowships while at the university. During the last three years the program has operated with five to seven graduate students on a three-year academic budget of $75,000 from a grant by Westinghouse. The Westinghouse program involved a budget in the order of $100,000 to $200,000 for the three years, and the programs with which the work has been connected at Westinghouse have involved amounts many times greater than the budget. Two doctoral theses have been completed at Stanford, one at University of Pittsburgh, and three more are in advanced stages now at Stanford. Three technical papers have been presented; two more are scheduled for this Fall (1964). Substantial parts of four graduate courses have been developed from the program. A continuation agreement has just been completed with Westinghouse.

From our point of view at Stanford, this program does a very important job in relating academic work to problems of the real world. The professor involved can keep his hand in the system problems in industry without being burdened by the administrative work which would be inevitable if he were to attempt similar work at the university. By providing introductions of the students to new areas, the company and the university can provide them with a range of practical experience they could not get in three or four years in industry on their own.

Although the work done with the company in some ways cuts down the independence of the university, the gains achieved by industry-university cooperation greatly outweigh the losses. By interleaving practical experience with academic work, the graduates can mature much faster than the usual graduate students and can assume positions of responsibility in industry in their late 20's and early 30's. A university program developing a professional field must have interaction with the real world to test the relevance of its program. In periods of rapid change in the real world, this coupling must be close if the feedback data are to be timely in modifying the academic program. Our Westinghouse Industrial Internship program appears to serve this function very well.

g. Recent Additions to the Stanford Internship Program in Systems Engineering

At present we are attempting to broaden our set of internships to include other companies and other areas. This summer (1964) we started a program for overseas industrial development in Peru. The object of this program is to involve our students with local students and local industries in Peru with the express purpose of supporting the growth of small businesses. As yet, the exact nature of this program has not been fully worked out. The university professor and his students cannot assume full responsibility for the program in the field, but he must be responsible for the project he undertakes. At present, we do not have an entity in the field which will provide as sharp a focal point as the research laboratory of a large company in the United States does. The problems encountered in this area provide a useful complement to those encountered in automation projects. The problems are those of regional planning, small business organization, development of new technology, assessment of social and political forces, and development of infrastructure support for industry.

A second type of internship started this year is with the Bonneville Power Administration. The problems are those of optimal operation of a government-owned facility to best serve the people. Recently anticipated additions to the hydro-storage from the Canadian-U.S. water storage agreements for Columbia River Basin development, and the high-voltage intertie between the Northwest and the Southwest, bring challenging new operational problems not encountered before.

Finally, this Fall we have started a program of one-year internships in Washington, D.C., called the Federal Engineering-Economics Internship Program. Under this program, mature graduate students take on projects in the executive branches of government much as have been undertaken by the Public Affairs Fellows of the Brookings Institution. The object of this experience is to complement their more specific experience gained in specific field ventures in previous internships. This project is still too new to permit much meaningful observation of its value.

h. Generalizations on Our Specific Experience

Our initial observations dealt with the growing importance of coupling between the academic community and the real world in periods of dramatic change in the real world. Professional schools appear to provide a valuable link between the academic programs in arts and sciences and the application environment outside the university. While this paper has stressed the role of engineering, it appears from initial consideration that management schools, education schools, and law schools should have the same sort of role to play as does engineering.

Because the professional training in our example was engineering, the mathematics and science programs in the arts and science school received primary emphasis. In many governmental and foreign trade and development areas, however, other areas of the academic community would have more relevance than the physical sciences. Economics, political science, psychology, sociology, history, and anthropology would be particularly relevant.

Though there appears to be little question of the value of coupling the university to the real world, there are serious questions of providing good entities in the field which assume the responsibility for the field program as the company does in the computer-coordinated system area. The university cannot undertake full responsibility for field programs without seriously degrading its academic function at home.

Stronger coupling between the university and the real world in several areas appears to be meaningful to both the university function and to solving problems in the real world. No complete plan has been developed but initial experiments are hopeful, and the functional needs and advantages are clear.

3. The Internship Program in Engineering-Economic Systems

In the postwar world the expansion of systems has proceeded at an unprecedented rate, so that today's engineers and industrial leaders must bring to system design a much broader range of sophistication in both technical and non-technical areas than ever before. In order to prepare young engineers to assume responsibility and to reach an early productive level in industry or in the field, the university is faced with the problem of devising adequate training procedures for system design--the backbone of management and engineering--along with the broad range of technical competence provided in conventional science-oriented coursework.

System design experience cannot be acquired in the university laboratory in any meaningful way, for the necessary industrial environment cannot be reproduced in the university without destructive attenuation. On the other hand, this training must be coordinated with the academic framework and occur concurrently with technical training if optimal pacing in the maturation of trainees is to be obtained.

a. Internship Program

For these reasons, Stanford University has conceived a program somewhat analogous to the medical internship, whereby graduate student interns learn by doing individual projects in a real-world situation--in the industrial plant or research laboratory, overseas development corporation, government agency or bureau, or other field locations.

Known as the Internship Program in Engineering-Economic Systems, a pilot program has been instituted in cooperation with the Westinghouse Company and has been in continuous operation since 1961. It has been shown to be feasible, practical, and to have profitable results for the participant organization, the students and the University, provided the planning for it is adequate and the selection of problems and people involved is carefully made.

(1) Advantages to Industry or Field Organization. From industry's point of view, a unique contribution can be made to a certain type of system problem by an intern. In the research or advanced planning sections of numerous companies, problems are encountered that cannot be solved on the basis of practical experience, which are technically unconventional and uncertain enough in outcome so that they are particularly well suited to the backgrounds of individual interns or academic teams. Indeed, the greater flexibility of the graduate students--their close familiarity with a broad technical field, their fresh approach and lack

of bias--can be a positive advantage in finding solutions and making a significant contribution to technology. Moreover, receiving much lower salary than their industrial counterparts, these students can be employed profitably in projects which have less certain or less immediate payoff. For instance, the cost to the company annually for the half-time services of a professor and a team of three to five students would be less than the usual research organization budgets for two members of its technical staff. In addition to receiving the benefits of the technical work done by these teams, the company is in a favored position to hire the already company-oriented student upon his graduation, having observed and participated in his development into a mature and productive technical man well acquainted with practical engineering from the start of his employment.

Although industry has been used here as an example, the advantages pointed out can accrue as well to any field organization participating, such as a government agency or bureau, overseas development corporation, or other.

(2) Advantages to the University. From the point of view of the University, along with providing essential practical experience as part of the academic program, the internship program can attract both superior professors and superior students. Many professors, experienced in the field and really enjoying work with practical problems, choose to remain in academic life because they prefer to deal with the technical, rather than the administrative, aspects of system engineering. Such an activity allows them to "keep their hand in" practical problem-solving, at the same time developing the system field from a theoretical point of view. The program offers a great advantage over typical consultant arrangements in that the professor's time for consulting is severely curtailed and short-term. As with the professors, top students are also attracted by the chance to work on a challenging industrial program concurrently with the academic program.

(3) Advantages to the Student. For the student, such an arrangement is invaluable. He would probably spend five years on his doctoral program with about two years of it spent on applied problems in the field. Economically, he would neither gain nor lose, but at the end of five

years, he would be able to move ahead much faster in the industrial world, because his practical training would be much more complete and more effectively correlated with his academic training.

b. Details of the Program

The internship program in no way substitutes for university classroom work or for thesis research. It is designed to complement academic work not only in content, but by structuring the learning process in time, in order to achieve the most desirable interaction of these separate areas of equally essential knowledge.

The academic team is composed of one professor and about five students. The professor serves as a staff consultant to the company, helping to select student projects and monitoring the students' professional development. He helps to advise students, but does not direct or supervise them. He carries on his own project to tie together the summation of student activities at the company with their associated program at the University. He spends all summers at the company or in the field, and two weeks per quarter, on the average, during the academic year. From one-quarter to one-half of his time at the University is spent on research associated with the company problems, varying depending on the situation.

Some students will be involved in doctoral programs, others will be involved in master's programs. All programs profit by having the student spend the summer after his bachelor's degree on an orientation program in the plant. Also the student should take full-time coursework for his first two or three quarters at the University so he can get adequate background to be effective in field work and research. After the first period of several quarters at the company, the student will usually spend on the order of half-time on classroom work and half on research during his period at the University. Generally, the work done at the company is project-oriented casework. The research work done at the University is concept-oriented casework in the early stages of a man's course and later it is thesis research if he goes on a doctoral program. The program is designed to be useful to both master's and doctoral programs, and many industrial companies and field contacts will involve both doctoral and master's students. It should be noted that students from all engineering disciplines, operations research, economics, political science, and business are expected to be involved in the internship program.

Each student will report to a company project leader or full-time field worker while at work. His work will be individual, and he will be subject to all company regulations including patent assignments and security matters, receiving work reviews and merit increases when warranted.

It should be noted that after the student has completed at least two quarters of coursework, the scheduling for his location during the program is widely flexible, varying according to the situation. Good projects cannot be arbitrarily scheduled; thus, the particular program set up will depend upon the readiness of the project in which he will be involved.

APPENDIX D. THE USE OF CASE STUDIES IN THE ENGINEERING PROGRAM

1. Introduction

A very promising development in engineering instruction which is being introduced experimentally at Stanford and several other schools is the use of cases. At Stanford experimentation with cases for engineering has centered in the Design Division of the Department of Mechanical Engineering, but the techniques have obvious applications to other disciplines. They provide a way of getting a type of reality and interest into engineering instruction throughout the program which can be very helpful in motivating students, as well as in drawing attention to particular areas of engineering interest. The Space program provides a wonderful area for the development of cases, at the same time bringing Space into the classroom in a way that will attract student interest.

Regardless of whether Space-related case material is made available through NASA in-house effort, or with the use of university talent (and NASA support), the resulting studies would be useful at many schools and in both graduate and undergraduate programs. The development of an engineering experience into a suitable case for classroom use requires substantial effort, but a library of cases, once prepared, could be widely used to bring the excitement of the Space program to classrooms in interested schools regardless of the presence or absence of graduate research in related areas.

The explanatory material which follows carries a bit of the flavor and enthusiasm which casework develops in the classroom. It was prepared by Karl H. Vesper of the Design Division at Stanford for presentation to the directors and visitors at a meeting of the Commission on Engineering Education held on February 27, 1965, in Washington, D.C.

2. Cases for Teaching Engineering (by Karl H. Vesper)

Perhaps the best place to begin in discussing cases for teaching engineering is to give a meaning for the term "case." It is a term used by many people and used very loosely. To some a case is almost any engineering problem given in school. To others it may be a journal article, or a patent description, a piece of broken hardware, or a story told by a professor. One of my friends, perhaps I should say one of my former friends, suggested that cases might somehow be connected with operation of a distillery. With your permission I would like to reject all these definitions for purposes of the present discussion and develop a different one.

Let us digress for a moment to the field of law. I don't know how many of you have been to law school. But all of you study law. When you apply for a driver's license you must read the motor vehicle code. When you start figuring your income tax you read the internal revenue laws. Generally you read no more than you absolutely have to because laws don't make particularly interesting reading in themselves. They only become interesting when they apply to a specific situation in which someone is involved.

Law schools appreciate this fact. And it is one of the reasons law students are not expected to spend too much of their time reading statutes during the three years of study required for a law degree. If law students had to read statutes for three solid years, most of them would probably defect. Instead, they study law as applied to real-life situations, the way you and I study law, and they find it very interesting. These real-life situations are presented to the students in the form of "cases."

An example of a law case is one entitled "Cooper vs. Greeley," found in a textbook by Gregory and Kalven entitled "Cases and Materials on Torts." This case describes a situation in which James Fenimore Cooper sues Horace Greeley for libel. Greeley's paper, the New York Tribune, published an article about Cooper which Cooper didn't like. Cooper threatened to sue the Tribune for implying that he was "ungenerous, ungentlemanly, and inhuman."

The Tribune wrote another article replying that if Cooper sued it would certainly be in New York City and not in Cooper's home town of Otsego, because Cooper was known by his neighbors in Otsego.

Cooper decided to file suit about that statement also.

Greeley asked that the case be thrown out because he said that Cooper had a reputation in Otsego of being a "proud, captious, censorious, arbitrary, dogmatical, illiberal, and litigious man with a bad reputation."

Cooper retorted that Greeley should not expect the court to heed such aspersions unless each of them was specifically proven. The judge disagreed with Cooper, but nevertheless his verdict in this case was that the matter should be brought to trial. That's where the case ends. The book doesn't carry us further.

From studying such situations as this, law students learn what it is they are supposed to know as lawyers.

Some business schools and medical schools also teach their students using situations involving specific people drawn from life outside the classroom and presented in the form of cases. But business and medicine are different fields from law, and in using cases each imposes its own peculiar twist of emphasis. In business there is less concern with precedent than in law. The businessman who over-emphasizes precedent may fall behind his competitors. Consequently, business schools emphasize to their students that each business case should be analyzed on its own merits, regardless of conclusions reached in prior cases.

In medical schools there is another twist, the objective being to develop skill in diagnosis and prescription. Diagnosis particularly receives more emphasis in medicine than it does in business or law. But again the cases involve specific people in specific situations.

Now let us look at some specific situations in engineering. Jack Wireman is a mechanical engineer about 40 years old who works for a company of 125 employees called Task Corporation in Anaheim, California. His company makes electric motors among other things, and these motors are usually custom designed for special applications where very high performance, such as high power per unit weight, is required. Consequently, the motors are very carefully designed and sell for a high price.

A contract for 200 such motors was recently received by Task Corporation and signed. Terms of the contract required demonstration that the motors would run for 2500 hours without failure. The first motor was shipped and installed in the customer's test stand. When it broke down after 1800 hours with a burnt-out bearing the customer was somewhat upset. Early the next morning Jack Wireman got a telephone call. The customer reminded Mr. Wireman that a firm delivery date had been set in the contract and asked, "What are you going to do about it?"

Here is an engineering problem situation. Why not describe this situation to an engineering student and ask him what Wireman should do? Let the student check the loads on the bearing, then turn to the bearing manufacturer's catalog and compute the theoretical design life. Let him examine pictures of the failed bearings and drawings of the assembly to find possible causes of the failure, and then come up with a scheme of action. In other words, let the student relive the situation through a case.

After the student has developed his answer we can tell him what Wireman did. From the catalog Wireman found that the design life of the bearing was 6,500 hours, or 2-1/2 times the requirement. Next he looked for other possible explanations of the failure but could not find anything convincing. So he called for help. He wrote the manufacturer of the bearing, who responded with a confident reply. The manufacturer's diagnosis was given as insufficient lubricity, and his prescription was to install a heavier bearing.

So Wireman installed the heavier bearing, one which had a design life of 19,000 hours, although it puzzled him somewhat that lubricity should be a problem when the bearing was running fully immersed in standard hydraulic oil, and he couldn't see why a 19,000-hour life bearing should be needed for a 2500-hour application. But he did as he was told ... and the 19,000-hour bearing failed after 700 hours.

Now if you will consider, 1800 hours is about 75 days, and 700 hours is another 30 days. On top of that there was the time taken for teardown, seeking advice, and reassembly, so about 4 months had passed in the testing and there was still a 2500-hour proof test to be run ... after the problems were solved. The customer was building million-dollar airplanes in which this motor was required, and he was starting to become nervous. The Task production department was manufacturing parts. Throw in the fact that these motors cost nearly $1,000 apiece and Task Corporation is a small company striving to break even after some years of losses, and it's clear that again we have a problem situation, one in which those of you from industry will recognize some familiar strains.

Well, now what should Wireman do? He can't waste time, and he can't waste money. Why not ask the student for some more advice?

More advice is just what Wireman asked for. He called on two consultants, one a professor at Cal Tech and the other a bearing expert from Ohio, and asked them what to do. They both analyzed the data of the case and made recommendations. Both of them disagreed with the bearing company. However, they also both disagreed diametrically with each other. One gave an extensive analysis showing that a still heavier bearing should be used. The other said a lighter bearing should have been used in the first place.

From these two analyses and his own, Wireman began to learn some things about ball bearings, and some things that aren't taught in textbooks. Possibly the student could learn some of these same things in the same way by joining in Wireman's struggle vicariously through cases. But notice an important difference. For Wireman the struggle was stretched out over a period of months. Most of his time during these months was spent on relatively uninstructive activities, matters of routine, and repetition found in all engineering projects. The most instructive episodes of his adventure occurred in a matter of minutes. Those are the minutes which the case should give the student.

The next thing that happened to Wireman was that another of the 19,000-hour bearings failed at 650 hours. Under the pressure of the customer and amid the conflicting experts Wireman felt compelled to think through all the evidence to his own solution. He conceived a bearing which was a compromise between the various pieces of advice, and he was able to find something like it in the catalog of a second bearing manufacturer. He had this bearing installed, it ran for 2500 hours, and Wireman has lived ever after.

I won't say happily, because Jack Wireman still isn't sure exactly what was causing those failures. And it can be a point for debate as to whether he did the most logical thing or whether he was just lucky on his final stab. Perhaps it's enough to say that it worked. But if you ask Wireman what he would have done if in fact that last bearing had, for some reason, not worked, you will see an expression of pain.

This is one case we used last year, but it isn't really typical because so many variations are possible. I've brought along some copies of another case which you can take home as a sample if you like after the meeting. It was taken from the Hewlett-Packard Company and involves a problem in creativity, rather than one in failure like the one I just described.

A total of 16 cases was finished last year and they represented quite a variety of styles and sizes. This year we plan to revise and improve some of these and to write additional new ones to double the total number available. We plan also to prepare and distribute a selected bibliography listing and briefly describing these cases and also engineering cases developed at other schools. If any of you would like a copy, we'll be happy to send it.

The way we produced these cases was to employ graduate research assistants as casewriters to do most of the legwork and writing. They reported to me and I did most of the editing. But final choice and editing was performed by a professor so each case was tailored to definite teaching objectives. This procedure got us over a serious stumbling block, namely, that professors generally don't have time to write cases themselves.

The professors were mostly satisfied with the cases written in this way, and consequently we feel that this experience disproves the myth that only professors can write good cases or that only those who experienced the case situations can describe them. In fact, one professor told us this procedure produced better cases than he could write from his own experiences, the reason being that in writing cases from his own experience he is too biased by his point of view concerning the answer to describe the problem objectively.

Another myth which our experience apparently disproved is that a professor can only teach a given case if he personally experienced the problem. None of the cases used last year were taken from the experiences of the professors who taught them. One professor summarized his attitude this way: "I feel I am a more competent engineer than my students because I have more experience, and that they can learn from me if we work on problems together. Therefore, I prefer the challenge of new case situations, ones which I have not seen before."

The cases were used last year in seven different courses at Stanford, ranging from freshman through graduate level. They also were tried in senior courses at UCLA and at the University of Santa Clara. Some cases served as one-day homework assignments. Others provided the basis for projects which took all term. Several of the cases were used more than once, and some were also used in courses other than those for which they had initially been written. For instance, one case originally designed as a dimensioning problem for the freshman drawing course at Stanford was ultimately used in a graduate course as a problem in stress analysis.

The ways in which the cases were used were entirely up to each professor, and the most striking result was the variety of viewpoints which emerged. Some saw cases as primarily a way of stimulating interest. Others saw them as a way of illustrating professional practice, or a way of letting students experience practice in accelerated fashion. Still another viewpoint was that cases are primarily a means for developing students' judgment.

Techniques of using cases in the classroom also varied among the professors. Sometimes cases were used as a basis for lecture, other times as a basis for class discussion. And they were used with various combinations of lecture and discussion. Our feeling at present is that this is an area of case pedagogy where substantial exploration remains to be done. It is a hard area to explore because most of us are so strongly controlled by our habits when we go about conducting a class.

Now, how about the results? Experiments like these are not easy to evaluate. We can look at the response of the professors who tried teaching with the cases, and then we can look at the response of the students who used them. From there on it's a matter of opinion.

Perhaps most significant among faculty reactions was the fact that the demand for cases now substantially exceeds supply and the gap is widening. In all courses where cases were tried the faculty expects to continue using them. Based on a one-week trial in a senior machine design course, the University of Santa Clara has also decided to try cases in its freshman drawing course and to have one of its professors devote next summer to writing cases in our program.

Occasionally among the faculty an unexpected remark was heard. For instance, one electrical engineering professor who had no working connection whatever with the case program remarked,

> "Ever since I have been counseling students of electrical engineering I have heard nothing but complaints about the freshman drawing course. Students haven't seen any value in drawing for electrical engineers. Generally, I have advised them to postpone taking the drawing course until the last possible moment, hoping the course would be dropped as a requirement. This year I was puzzled not to hear any such complaints. And on two separate occasions when I commented to advisees that it was too bad they had signed up for the drawing course earlier than they had to, they replied, 'What do you mean? It's a terrific course.'"

The only major change in the drawing course this year was the substitution of six cases for a large proportion of the traditional teaching materials.

The dropout rate in the engineering drawing course this year fell by a factor of four. The instructor and teaching assistants of the course commented that students showed an unprecedented amount of interest in the work and asked unusually many questions. One day the instructor was surprised to find a formal lecture in progress during his drawing laboratory period. It turned out that the lecturer was an aeronautical engineering graduate student who had been invited by students and assistants of the course to comment from his industrial experience on helicopter design, which happened to be the subject of the case presently under study.

We also tried gathering student reactions through anonymous questionnaires. The two most extensive questionnaires were the one given in the Stanford drawing course, where cases were used throughout the quarter, and the one given at the University of Santa Clara in the machine design course, where cases were injected without fanfare for one week. In many ways these courses were quite different from each other. The drawing course included about 111 male students and one girl, most of them freshmen, while the machine design course had only 13 students, all of them seniors. The questionnaires were aimed at overall evaluation of the courses and were not selectively focused on the cases. We did not want cases to seem like they were getting special treatment. Among other things, students were asked to rate the educational value of various teaching approaches used in the courses. The results were as follows: in the Stanford drawing course the lowest rating went to the textbook, the next lowest went to the laboratory session, the middle rating went to the textbook exercises, second highest rating went to the lectures, which included discussion of the cases, and the highest rating went to the cases. In the Santa Clara machine design course, the lowest rating went to the lectures which did not include case discussions, the second lowest rating went to the textbook exercises, the middle rating went to the laboratory design project, the second highest rating went to case discussion which did not include lectures, and again the highest rating went to the cases.

The students were also asked for their comments.

The value of the cases based on student comments are as follows: "Required initiative, ability to think for oneself." "It gave us a feeling of usefulness and put us up against actual problems." "Broader picture of problem, less boring." "Showed you what engineering is really like, what engineers really do." "Showed how to attack design problems."

Students were also asked to state what they considered to be the main disadvantages of the cases. Encouragingly enough, some of them didn't see disadvantages, and made statements such as "nothing to compare with but felt they were good." Others, more resourceful, made some comments as follows: "Too much time trying to discern the limits of the problem." "The ambiguity of criteria on which we were to base our solutions." "Too many in such a short time, should go into more detail." "We weren't technically able to cope with the cases." And finally we had one comment from the freshman drawing course as follows: "I saw no disadvantages at all. But then what girl would in a class with 100 men all to herself?"

Although these results were rather encouraging they do not by any means suggest either that cases are the answer for all engineering instruction or that the job of exploring cases is now approaching completion. It appears that cases will never be as effective for teaching mathematical procedures as conventional methods are. And cases cannot let a student know the feel of a welding torch the way a shop course can. On the other hand, conventional methods may not be able to give a student working experience in a dozen major projects a month as cases can.

Cases seem to work from freshman through graduate level, but at what level and in which courses can they contribute most? We don't know. But we all somehow ought to find this out.

The thing that most needs doing right away is to build up a larger number of cases from which instructors can choose for their special needs. With a large supply we won't have to use the same cases over again in a given course, a procedure sometimes beguiled by fraternity files. Production of cases at more schools and interchange of cases among schools would be the best way to build the supply.

We have received requests for cases in many subjects, such as sanitary engineering, where no cases at all seem to be available yet. And beyond existing courses are the new subjects for case development mentioned by Dr. Bollay, such as technical problems of underdeveloped areas.

We've only scratched the surface at this point. But it seems to be the surface of a rich and widening vein. We'd like to thank those of you from industry who let us have data from which the cases must be made. We are grateful to those of you from foundations and government agencies who help us get the financing we must have to begin. To you from other schools we'd like to say here is a field of promise. More and better cases are in need. And better ways to use them must be learned. The part you choose to play can help us all.

APPENDIX E. THE STANFORD JOINT SERVICES ELECTRONICS PROGRAM AS AN EXAMPLE OF "PROGRAM" FUNDING OF UNIVERSITY RESEARCH

1. Introduction

In Sec. IV-F a form of administrative organization has been outlined which could be applied to an interdisciplinary program in engineering space research of the type at Stanford. The specific suggestions made in that section were based on consideration of previous Stanford experience in research administration, on consideration of faculty attitudes toward research and its administration, on investigation of the experiences of other universities in administering programs having similar features, and upon certain general principles of effective management. In forming this judgment with respect to the merits of various administrative mechanisms for university research support, the historical experience of the Stanford Engineering School is of special interest.

In this appendix an independent commentary on the Stanford experience with the administration of discretionary research funds in electronics is presented from the viewpoint of the administrator of those funds. Based on that experience, some specific suggestions are made concerning the framework within which multidisciplinary NASA support might be arranged, and the manner in which project and institutional support might be integrated.

2. History

Stanford is one of several universities carrying out basic research in electronics under the joint sponsorship of the Army, Navy, and Air Force through the Joint Services Electronics Program (JSEP). The general arrangement calls for equal financial participation by the three military sponsors. Funds are transferred within the military, with those for a given university being channeled through a single Service selected as the contracting and administrative agency for that school. The total program is treated as an entity within the military agencies; the component programs of the several schools are monitored by a single DOD Technical Advisory Committee (TAC) composed of service representatives (who can be civilian or military) selected from within the agencies directly concerned with the program.

The Stanford JSEP contract is handled by the Office of Naval Research. It was formed by uniting the sponsorship of several in-being programs within a single-contract framework. Thus, at its inception (in the late 1940's) this contract supported substantially all of the Government-sponsored research carried out by the faculty and graduate students in the Department of Electrical Engineering. In many respects, this period represented a high point in smooth and efficient organization, conduct, and administration, in large measure because the bulk of the total research program was single-contract funded. Today, there are almost 90 active contracts and grants in the Stanford Electronics Laboratories (SEL), of course for a much larger total volume. The Joint Services Program continues as an essential core component of the Stanford research in electronics. It has grown substantially over the years but not in keeping with Department expansion in students and faculty; today it represents about 10 percent of the research volume within the Stanford Electronics Laboratories.

This appendix examines the experiences gained with this contracting mechanism over a history in excess of 17 years. Why the decline in percentage of total research support that it represents in view of the many demonstrated values of the JSEP arrangement? What can be learned with respect to the institutional grant (program) vs direct support (project) controversy and about the relative attractions of grants vs contracts? In particular, how do the experiences relate to the support of university research by NASA? The examination is justified by the fact that the JSEP component of the SEL effort has consistently been the most productive element per support dollar in terms of research impact on the outside community, in terms of the generation of new ideas subsequently developed individually by the Services, and in terms of the provision of research experience for Ph.D. candidates.

3. Pertinent Aspects of the JSEP History at Stanford

There is a remarkable diversity as found at the several participating universities within the broad JSEP structure. Researchwise, there may be an emphasis on electronics, or physics, or systems. In the fiscal sense, the JSEP exists at some schools largely as an institutional grant accounting for a very large percentage of the total research volume. At Stanford, the format is that of a direct contract with the Office of Naval Research. In its initial Stanford formulation it supported research program components that had been earlier arranged, individually, through normal principal investigator-sponsor negotiations as to general intent, scope, timing, budget, etc. Program composition is now primarily a school responsibility (though broadly monitored by TAC) and it now carries many of the flexibilities normally associated with the institutional grant (as will be discussed later). Its conduct has been marked by a farsighted attitude on the part of the Technical Advisory Committee as a whole and by the Office of Naval Research specifically as regards administration of the Stanford contract.

The concern in this appendix is with contractual and administrative aspects. However, it is well to note that the longevity of the program (implied and demonstrated but not legally incorporated), its growth pattern at the individual schools, and its extension to other universities are indications of a successful history in attaining the primary scientific aims of the program. The average growth in funding in a given school has not been as large as the aims and successes of the programs would suggest. However, the introduction of additional participating schools to the total program has been a logical use by the sponsoring agencies of the gains in the total JSEP fund. The basic objective is to seek excellence in electronics research contributing to a basic technology supporting the long-range interests of the Department of Defense, and to accomplish this within an administrative pattern in full conformance with the academic aims and traditions of the university. The program structure and talents involved constitute a framework for more direct support of the DOD in an emergency situation (as demonstrated in the Korean War).

Some salient points in the JSEP practice at Stanford follow. These have freely evolved in a long history.

a. The Technical Advisory Committee allows full latitude to Stanford as regards generation of specific research undertakings. There is an initial broad understanding reflected in a short "Work Statement" in each annual contract renewal expressing the general scope of the program, some focus in research interests, and a general operating philosophy. An investigation can be undertaken without prior TAC approval. The program is subject to an annual, after-the-fact review by the Committee. Total funds, of course, are fully specified and the program is subject to normal audit. A single committee handles all of the university programs; in this sense the programs are placed in a certain healthy competition. The Committee is in a position to express its assessment of the programs through the annual renewal process itself, and by the relative allocation of funds among the several university programs which constitute the total JSEP.

b. The Technical Advisory Committee seeks to serve in three basic ways:

   1. It handles the administrative arrangements involving the several DOD participants--inter- and intra-Service coordination, funding, reporting, etc.

   2. It provides the broad monitoring of research progress described in (1) above.

   3. It serves as an interface in technical matters between the university and the military agencies through which the important areas of current research interest within the military can be expressed to the university, and through which important research results growing out of the university programs can be brought to the attention of interested groups within the military.

   The first function can be performed successfully almost independently of program size. But the next two become increasingly difficult as programs grow in terms of numbers of participants and, particularly, with the expanding scope of the research. All three functions can be handled successfully when programs are small; they are carried out with reasonable success when the program represents a modest component of the very much larger research total which now exists at Stanford. It would be an impossible imposition on the Technical Advisory Committee to expect it to serve as the total program monitor and primary communication mechanism with respect to the full SEL program. Even at the present level, it has been found necessary at Stanford to augment the transfer of technical information by additional, planned efforts. In short, the JSEP framework could handle more than the present 10 percent of the electronics research volume at Stanford successfully; it could not handle the total program effectively.

c. Because "flexible" funds of the JSEP character are both in great demand and short supply, several ground rules have evolved to assure the most productive assignment:

   1. The inherent promise of the research is, of course, of paramount importance.

   2. Funds are restricted to the support of programs of faculty and Ph.D. candidates, i.e., for on-campus research carried out with the talent available in the academic environment.

   3. A general program balance is sought in keeping with the scope of the match of University-Sponsor interests expressed in each renewal of the JSEP arrangement.

   4. There is a deliberate accommodation of new research ideas or "spinoffs" which, though particularly promising, often fall outside the scope of other current research support.

   5. A fraction of the research support is reserved for two essentials: (1) for promising "start-up" research proposed by new faculty, and (2) for terminal support for dissertation research initiated under a program since completed as regards its principal research aims. The products of such research are credited to the JSEP program.

   Program funds are allocated within SEL by a faculty committee chaired by the Director. Faculty members are invited to submit simple (one-page) research proposals to the committee.

d. It has proven possible to carry out the disposition and administration of funds within the laboratory structure with a minimum of friction. The program is popular with the faculty; it serves well the not infrequent combination of the skilled researcher but inept salesman. There would be more friction were it not for the fact that at Stanford the JSEP support source represents but one component of the total program. It does represent a source which can be approached conveniently and with a minimum of faculty negotiation. But it is not the only source and the faculty is often encouraged to seek alternative program support outside the JSEP structure through direct contact with Federal agencies. Indeed, the latter route must be followed if the program needs are large since the JSEP funds are quite limited. Many types of research fall outside of the JSEP purview. A sensitive faculty member who wishes to have his proposal judged outside his immediate (Stanford) environment is free to submit his program through regular channels. A faculty member whose proposal is not accepted within the JSEP framework can pursue the normal channels to outside agencies.

e. While the JSEP component is a relatively small fraction of the total research support in SEL, it is a substantial and significant component. The ability to negotiate for and administer such a block of support in a single operation is undeniably of great value. The longevity implied in the arrangement (and amply demonstrated) is enormously useful in long-range planning of university research. There is a certain inertia in JSEP funding, in part due to the doctrine of equal participation by the three Services--the least affluent in a given year tends to set the pace. But there are compensating stability aspects which have proven to be of real long-range value.

f. A particular aspect of the JSEP contract mechanism at Stanford requires special note. While the basic program itself is operated strictly on the basis of equal participation, the latitude exists for program add-on's in the interests of emphasis or acceleration of a specified experiment by a single agency. Thus the contract has been used as a basic structure in the contractual sense. It is often a matter of considerable convenience for Federal agencies to transfer funds into an existing contract without the often extensive negotiations and time loss attendant to the development of a new grant or contract. There is a corresponding saving within the university structure. It has been possible for groups within the Navy, for example, to transfer funds expeditiously to the Office of Naval Research, and the inter-Service transfer of research support has been similarly demonstrated.

The transferred funds do not become part of the JSEP activity in the technical program sense--the add-on support is typically earmarked for a specific research effort and is so treated by the University. In other words, the support is directed to an identified Principal Investigator for a particular research objective and the Principal Investigator maintains a direct technical program contact with the agency supplying the support component. This add-on option has been of great value in getting research under way quickly. It is a matter of major administrative convenience. Unfortunately, it is not exploited to the extent that it once was. There are two reasons. As the interest in university research broadened throughout the DOD, it became increasingly difficult to establish the contacts (technical) and interchanges (administrative and financial) within the military organizations necessary to such cooperative action. Equally important, it has proven difficult in some instances for the non-JSEP military groups to retain (within their own establishments) credit for funds transferred out of their agencies and an identification with research results accruing from such action. These are matters subject to control, particularly when the total scope of the operation would be retained within a single Federal agency, e.g., NASA. In view of the values, the practice calls for careful consideration.

The supplementary fund practice has been used to support work quite unrelated to the JSEP research itself, to cover particular exploitations of that program of special interest to a single Service, and to provide for major developments of the JSEP research, the funding of which would work a serious financial hardship on the on-going program.

g. In a real sense, the JSEP arrangements at Stanford represent the blend of the institutional grant and direct project funding mechanisms. The experiences have shown the very real value of certain aspects emphasized in the institutional grant. But there are values, as well, in direct project support which assume particular importance in engineering research (which is a focal point in the Stanford Electronics Laboratories program). The program should be subject to stimulation from the outside as regards emphasis. Certain aspects of engineering research place a premium on responsiveness. It is essential that there be a degree of real-world contact guaranteeing an effective two-way interchange of information and experiences.* This is particularly important in the case of certain sponsors--DOD, NASA, etc. It might not carry the same importance in all cases (it would not with respect to the fundamental aims of the National Science Foundation). There is nothing about the institutional grant which excludes the establishment of the university-sponsor relationship described; <u>the relationship is assured in the direct research project support arrangement</u>.

The current mix of research support in the Stanford Electronics Laboratories is, in part, the result of an evolution conditioned by the many forces described herein. While the experience has been with electronics research, it is surely applicable to other disciplines and, indeed, to interdisciplinary programs.

4. <u>A Framework for University Research Funding</u>

There is a tendency in considering support of university research to dwell on (1) grants vs contracts or (2) institutional grants vs direct project support. The grant vs contract comparison is relatively meaningless until the terms of each are defined. There have been contracts written to support university research which contain all of the practical flexibility normally associated with grants; the reverse is also true. There is no question but that the grant is basically an attractive mechanism for university research funding (unless, of course, an overhead limitation precludes full recovery of research costs on an audited basis). In short, there is no historical experience at Stanford

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*There is no intent here to associate "engineering research" with "applied research." There is an intent to link engineering research with the community in such a way that the results can provide an optimum base of basic research results assisting the generation and development of new concepts and instruments of maximum interest to the research sponsors.

arguing for the exclusion of the contract or the insistence on the grant. There are experiences suggesting the grant to be the more favorable tool in certain instances and the contract to be the more realistic mechanism for support of programs of certain character, e.g., in which the end item is a piece of experimental hardware.

As regards the second discussion topic--the institutional grant vs project support--it is important to note that the two are not in direct competition in a number of important regards. To a meaningful degree, the two forms are complementary and it is useful to examine a blend of the two as the optimum framework for the support of an engineering research program.

The Stanford experiences as earlier outlined suggest that major supporters of engineering research in universities consider a formula in which composite programs:

1. Be handled primarily (perhaps two-thirds to three-fourths of the total research volume) through direct project support individually negotiated.
2. Involve a complementary step-funded institutional support component negotiated in an amount generally set by the NASA-supported project research as established above--possibly one-fourth to one-third of the recent aggregate, retotaled annually.
3. Make use of a renewable (long-term) master grant* accommodating both the "institutional" funding (as above) and the bulk of individually negotiated projects on a "task" basis. Within this arrangement, a new project, as negotiated, would call for add-on funds directed through the master grant to the principal investigator for an agreed-upon purpose and with an understanding as to performance time. The principal investigator would deal directly (in scientific matters) with the supporting government group; the university would be responsible for administering funds in accordance with the "task" anticipations. Technical reports would be handled individually, but all experiments would be covered in a single status report scheduled (timewise) to the master grant date.
4. Continue the contract format which normally covers major mission-oriented research, often with requirements for subcontracting, unusual support equipment procurements, etc. It is strongly suggested, however, that the contractual practices developed for industrial relationships be adjusted in the case of university research to a form reflecting the different aims, opportunities, and environments.

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*Or suitably framed contract if agency rules forbid renewable grants.

The above suggestions deal principally with the format of the research support arrangement. In a sense, they seek the "best of two worlds" in a balanced program guaranteeing the flexibility aspects so important to a full realization of the potential of the university environment plus a responsiveness, focus, and communication essential to the total mission.

The objectives are in line with the experiences enumerated in the earlier paragraphs. There are, of course, additional aspects--terms--which are important to the schools regardless of the basic form of the support arrangement. These would include, for example, the freedom to publish nonclassified material, full opportunity for graduate student participation, a flexible patent policy, a reasonable latitude regarding capital equipment acquisitions, etc.

The University would hope that any research support arrangement would, insofar as possible,

1. Be initiated on the basis of competence and be continued upon the demonstration of results.
2. Permit a full recovery of research costs on an audited basis.
3. Recognize the school as the responsible organization best able to establish its internal policies and practices.

4 January 1959 the space rocket will reach the area of the Moon.

The last stage of the space rocket weighing 1472 kilograms without fuel has a special container inside which there is measuring apparatus for conducting the following scientific investigations:

detection of a magnetic field of the Moon;

study of the intensity and of variations of the intensity of cosmic rays outside the magnetic field of the Earth;

recording of photons in cosmic radiation;

detection of radioactivity of the Moon;

study of the distribution of heavy nuclei in cosmic radiation;

study of the gaseous component of interplanetary matter;

study of the corpuscular radiation of the Sun; and

study of meteor particles...

For observation of the flight of the last stage of the space rocket it has installed on it:

a radio transmitter emitting telegraphic signals of a duration of 0.8 and 1.6 seconds on two frequencies of 19.997 and 19.995 megacycles;

a radio transmitter operating on a frequency of 19.993 megacycles with telegraphic signals of variable duration on the order of 0.5-0.9 seconds with the help of which the data of the scientific observations are transmitted;

a radio transmitter emitting on a frequency of 183.6 megacycles for use in measuring the parameters of movement and in transmitting scientific information to the Earth; and

special apparatus intended for creating a sodium cloud -- an artificial comet.

The artificial comet can be observed and photographed by optical means equipped with light filters which isolate the spectral line of sodium.

The artificial comet will be formed on 3 January at approximately 0357 Moscow time and will be visible about 2-5 minutes in the constellation Virgo, approximately in the center of the triangle formed by the stars Alfa Volopas, Alfa Virgo, and Alfa Libra.